Geojournal of Tourism and Geosites
ISSN 2065-0817, E-ISSN 2065-1198

Year XVIII, vol. 59, no. 2, 2025, p.551-562
DOI 10.30892/gtg.59204-1436

TOWARDS GREENER SKIES: EVALUATING SUSTAINABLE AVIATION FUEL ALTERNATIVES

Omar ALHARASEES
Budapest University of Technology and Economics, Faculty of Transportation Engineering and Vehicle Engineering, Department of Aeronautics and Naval Architecture, Budapest, Hungary, e-mail: oalharasees@edu.bme.hu

Dániel ROHACS
Budapest University of Technology and Economics, Faculty of Transportation Engineering and Vehicle Engineering, Department of Aeronautics and Naval Architecture, Budapest, Hungary, e-mail: rohacs.daniel@kjk.bme.hu

Anetta MULLER*
University of Debrecen, Hungary and Institute of Sports Economics and Management, Faculty of Economic Sciences, Debrecen, Hungary, e-mail: muller.anetta@econ.unideb.hu

Utku KALE
Budapest University of Technology and Economics, Faculty of Transportation Engineering and Vehicle Engineering, Department of Aeronautics and Naval Architecture, Budapest, Hungary, e-mail: kale.utku@kjk.bme.hu

Citation: Alharasees, O., Rohacs, D., Müller, A., & Kale, U. (2025). Towards greener skies: Evaluating sustainable aviation fuel alternatives. *Geojournal of Tourism and Geosites*, 59(2), 551–562. https://doi.org/10.30892/gtg.59204-1436

Abstract: The aviation sector is a major contributor to global carbon emissions, with increasing demands for air travel intensifying environmental concerns. Sustainable Aviation Fuels (SAFs) have emerged as a promising alternative to mitigate the carbon footprint of air travel while supporting the industry's sustainability goals. However, the adoption of SAFs is influenced by multiple factors, including environmental impact, economic feasibility, technical feasibility, and social acceptability. A systematic evaluation of these factors is essential to identify the most suitable SAF options for widespread implementation. This study aims to assess and prioritize sustainable aviation fuel alternatives using a structured multi-criteria decision-making framework. The evaluation focuses on identifying the SAFs that provide the most significant environmental benefits while ensuring economic and technical viability and gaining social acceptance. The study employs the Analytic Hierarchy Process (AHP) to prioritize four primary criteria - environmental impact, economic feasibility, technical feasibility, and social acceptability - and evaluate SAF alternatives. Data were collected from a diverse group of aviation experts, including pilots, air traffic controllers (ATCOs), engineers, managers, and researchers. Pairwise comparison matrices were constructed to capture expert opinions, and responses were aggregated based on job categories and experience levels for a comprehensive analysis. The results indicate that environmental impact is the most critical criterion, with carbon emissions being a key determinant. Among the evaluated SAF alternatives, Synthetic Paraffinic Kerosene (SPK) achieved the highest ranking due to its superior compatibility with existing aviation infrastructure and its significant environmental benefits. Hydrogenated Vegetable Oil (HVO) followed closely, praised for its operational feasibility within current airport systems. In contrast, Gas to Liquids (GTL) ranked lower, primarily due to concerns regarding its economic viability and the energy intensity of its production process. The study highlights the need to prioritize SAF alternatives that balance environmental performance with technical and economic feasibility. SPK and HVO stand out as the most viable options for reducing aviation-related carbon emissions and advancing sustainability goals. These findings provide valuable insights for policymakers and industry stakeholders, emphasizing the importance of investment in SAF infrastructure and supportive regulatory frameworks to drive adoption. Promoting SAFs will play a key role in reducing the aviation sector's environmental impact and supporting sustainable tourism practices globally.

Keywords: sustainable aviation fuel, analytical hierarchy process, environmental impact, economic feasibility, sustainability

* * * * * *

INTRODUCTION

The aviation sector significantly contributes to greenhouse gas emissions, particularly carbon dioxide (Cabrera and de Sousa 2022). With its ongoing expansion, mitigating aviation's environmental impact remains a critical challenge. A promising approach is the advancement of sustainable aviation fuel (SAF) (Bergero et al., 2023), which can lower aviation's carbon footprint while addressing the growing demand for fuel. However, SAF development is influenced by economic, technical, and social factors. This study on sustainable aviation fuels (SAFs) directly supports sustainable tourism (Fanni & Rezazadeh, 2018; Sutiksno et al., 2024) by addressing a key environmental challenge in air travel: carbon emissions (Qasem et al., 2024). Tourism heavily relies on air transportation, contributing significantly to its carbon footprint. In tourism, sustainability, green, and environmental aspects are playing an increasingly important role for both

* Corresponding author

tourists and service providers, a focus highlighted in several studies (Kyriakaki & Kleinaki, 2021; Refaat & Arafa, 2022; Al Dein, Fahmawee & Jawabreh, 2023; Esparza-Huamanchumo et al., 2024, Atshan et al., 2024). According to 2023 statistics, tourism travel accounted for approximately 50-60% (IATA, 2023; Tourism Organization, 2024) global air traffic, primarily involving short- and medium-haul flights, contributes significantly to carbon emissions. These routes often limit the potential for efficient fuel use and the application of alternative fuels.

This substantial share is significant because global air transport’s carbon dioxide emissions heavily impact the environment; estimates by the International Civil Aviation Organization (ICAO) indicate that aviation accounts for 2-3% of total human-caused emissions. Reducing tourism-related flights and adopting more sustainable fuels are therefore crucial for tourism’s sustainability. The sustainable aviation fuels (SAFs) examined in the study, such as Synthetic Paraffinic Kerosene (SPK) and Hydrogenated Vegetable Oil (HVO), are especially important for tourism sustainability as they offer options to mitigate the environmental impact of air travel. In doing so, they contribute to the sustainability goals of the tourism industry by reducing its carbon footprint and making eco-conscious travel options more attractive.

A primary barrier is the higher production cost compared to conventional fossil fuels, driven by factors such as feedstock availability, conversion technology, and economies of scale (Tanzil et al., 2021; Monte et al., 2022). SAF production costs are influenced by agricultural production, land-use policies, weather conditions, and global market dynamics, which affect both the availability and price of feedstocks (O’malley, Pavlenko & Searle, 2021; Mofijur et al., 2023). Certain feedstocks, such as food crops, also raise concerns regarding competition with food security, land conservation, and sustainability. Although SAF prices are expected to decrease as technology advances and production volumes increase, the economic challenge remains significant. Technical feasibility is equally crucial in SAF adoption. SAF must be compatible with existing aviation infrastructure, including aircraft, engines, and fuel systems, and it must meet rigorous fuel specifications such as energy density and combustion characteristics (Hileman & Stratton, 2014; Shahriar & Khanal, 2022). Additionally, the supply chain for SAF, which encompasses production, distribution, and storage, requires significant infrastructure development to ensure scalability and effective deployment.

Social acceptability (Kantenbacher et al., 2018) presents another layer of complexity. Public perception and acceptance of SAF play a vital role in its success. While SAF reduces aviation's carbon footprint, concerns exist over its impacts on water, biodiversity, and land use (Anderson et al., 2022; Chong, Chemmangattuvalappil & Thangalazhy-Gopakumar, 2023). Several promising solutions address the development challenges of SAF (Schmidt et al., 2018). Synthetic paraffinic kerosene (SPK), hydrogenated vegetable oil (HVO), and gas-to-liquids (GTL) are key examples of alternative fuels that can potentially reduce aviation's carbon footprint while remaining economically feasible and technically viable (Ram & Salkuti, 2023). SPK, produced via Fischer-Tropsch synthesis from feedstocks like waste oils, natural gas, and coal, offers compatibility with existing infrastructure. Similarly, HVO is a renewable diesel derived from vegetable oils, and GTL involves converting natural gas into liquid hydrocarbons, including jet fuel (Shahabuddin et al., 2020).

However, SAF development faces economic, technical, and social challenges (Martinez-Valencia, Garcia-Perez & Wolcott, 2021). High production costs, feedstock availability, and public acceptance are significant barriers. Addressing these requires a multi-stakeholder approach, involving collaboration between industry, policymakers, and the public (Ahmad et al., 2019). Moreover, the use of alternative feedstocks, such as waste materials or non-food crops, can mitigate concerns regarding land use and food production competition. Novel conversion technologies, such as Fischer-Tropsch synthesis and pyrolysis, offer the potential for greater efficiency and cost reduction (Montoya Sánchez et al., 2022).

Sustainable aviation fuels (SAFs), such as Synthetic Paraffinic Kerosene (SPK), Hydrogenated Vegetable Oil (HVO), and Gas-to-Liquids (GTL), play a vital role in reducing aviation’s carbon footprint, thus supporting tourism’s sustainability goals by offering eco-conscious travel options (Kuqi, 2018; Detsios et al., 2023). SPK, produced from various feedstocks, and HVO, obtained through hydrogenating vegetable oils or animal fats, meets severe aviation standards and closely resembles conventional jet fuel properties. GTL, produced by converting natural gas into liquid hydrocarbons, further expands sustainable aviation fuel sources. Ongoing SAF innovation and regulatory support remain essential to the industry’s decarbonization and broader adoption (Ram & Salkuti, 2023). The purpose of this study is to evaluate the preferences of different job categories and experience levels toward Sustainable Aviation Fuel (SAF) using the Analytic Hierarchy Process (AHP). The study involves two aggregated steps. The first step is an AHP evaluation of SAF based on job categories, which include pilots, air traffic control officers (ATCOs), aircraft engineers, aviation managers, and researchers. A generalized hierarchical model is constructed using the primary criteria of the current system, allowing for multiple levels of decision-making to develop evaluator preference loads for the assessment and weighting process (Alharasees et al., 2024 a, 2024 b,), resolve conflicts and uncertainties, and address missing information using other AHP functions.

The "Saaty Scale" is utilized to score missing data, generating matrices using a specific method. The second step involves an AHP evaluation of SAF based on experience level, which includes less experienced and experienced individuals within each job category. The same process is followed in constructing a generalized hierarchical model and resolving conflicts and uncertainties. This step helps to identify the preferences of less experienced and experienced individuals towards SAF within each job category. Overall, the aim of this study is to evaluate the preferences of different job categories and experience levels toward Sustainable Aviation Fuel (SAF) using the Analytic Hierarchy Process (AHP). By examining the perspectives of pilots, air traffic control officers (ATCOs), aircraft engineers, aviation managers, and researchers, as well as differentiating between less experienced and experienced individuals, the study seeks to uncover nuanced preferences that influence SAF adoption. Through this multi-criteria evaluation, the research aims to provide actionable insights that can support industry stakeholders, policymakers, and aviation professionals in shaping informed decisions, developing targeted strategies, and advancing SAF implementation to achieve environmental sustainability in aviation.

METHOD

The analytical Hierarchy Process (AHP) was developed by Saaty in the 1980s to enhance systematic evaluation and decision-making (Saaty, 1990). This methodology combines mathematical rigor with psychological insights (Alharasees & Kale, 2024). as detailed in his works from 1990 and 1994 (Saaty, 1994). AHP utilizes objective mathematical techniques to aid individuals or groups in reassessing their priorities during decision-making (Alharasees & Kale, 2023). By implementing AHP, users can effectively analyze intricate decision problems, leading to informed and sound conclusions. The AHP technique serves to evaluate and prioritize various options by establishing a decision hierarchy (Alharasees et al., 2022). This process involves assigning relative importance percentages to each alternative, thereby facilitating clear preference rankings. This structured approach is particularly useful for complex decision-making scenarios requiring a systematic hierarchy of options (Alharasees & Kale, 2022).

At the core of AHP is the subjective evaluation of alternatives based on established criteria. A significant element is the Saaty scale, which quantifies the influence of different factors on decision-making and assesses the relative significance of each option within the model. Figure 1 illustrates a flowchart of the AHP decision-making process, which includes identifying relevant criteria, evaluating and ranking options by their importance, converting subjective assessments into quantifiable percentages, and ultimately utilizing this information to reach a final decision.

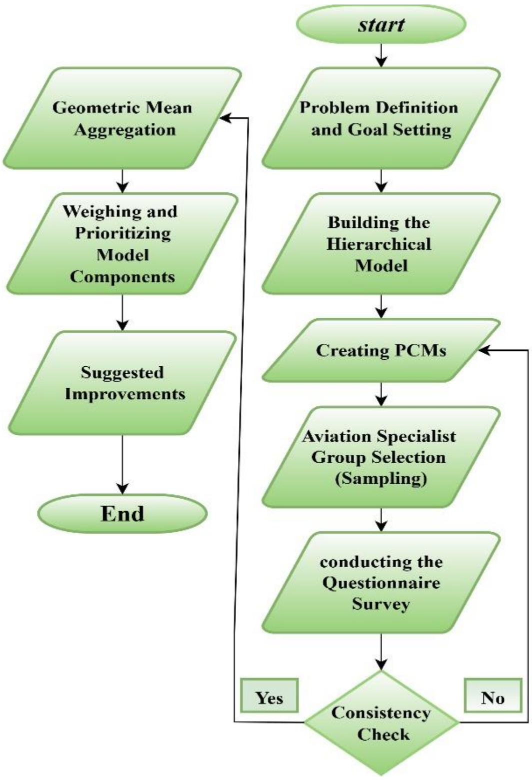

Figure 1. AHP method flowchart

The AHP method flowchart shown in Figure 1 can be used to evaluate the critical factors of sustainable aviation fuel (SAF) and suggest alternative solutions. The steps involved in using the AHP method for this purpose are outlined as follows:

1. The first step is to define the problem and determine the goal of the study, which is to evaluate the critical factors of sustainable aviation fuel and suggest alternative solutions.

2. The second step involves building a hierarchical model that contains the relevant features and characteristics of sustainable aviation fuel. The model consists of a hierarchy of decision elements that are arranged in a tree-like structure with the goal at the top, the criteria and sub-criteria in the middle, and the alternatives at the bottom.

3. The third step is to create pairwise comparison matrices (PCM) based on the hierarchy. These matrices represent the decision-maker's preferences between specific pairs of options and are created using a scale such as the Saaty scale. The elements of the matrix are positive, transitive, and reciprocal, indicating consistency.

4. The fourth step involves selecting aviation specialists or experts through sampling. The selected group should have a clear understanding of the decision-making criteria and be able to provide valuable feedback on the critical factors of sustainable aviation fuel.

5. The fifth step involves conducting a questionnaire survey to collect opinions and preferences from the aviation specialist groups. The survey should be carefully designed to ensure that the questions are clear and easy to understand.

6. In the sixth step, the consistency ratio (CR) of the PCM should be checked. If the CR of the PCM is less than 0.1, the process can continue. However, if the CR is greater than 0.1, adjustments should be made, such as reviewing the judgments made in the PCMs and considering the reasons behind any inconsistencies or gathering more data by conducting additional surveys or seeking expert opinions to improve the consistency of the PCMs.

7. In the seventh step, the PCM for each individual participant in each group is aggregated using the geometric mean aggregation method to obtain a single PCM that represents the preferences of the group. A single consensus matrix that reflects the overall opinions of the group is allowed by this method for the aggregation of multiple participants' preferences.

8. The eighth step involves weighing and prioritizing the model components. The weights are determined using the eigenvector method, and the prioritization is done using the weighted sum method to determine the critical factors of sustainable aviation fuel.

9. The final step involves suggesting alternative solutions to improve the current situation based on the results of the AHP analysis. The results of the AHP analysis can be used to identify the strengths and weaknesses of the current system and suggest possible improvements to make sustainable aviation fuel more efficient and sustainable.

The creation of pairwise comparison matrices (PCM) is a fundamental component of the AHP method. These matrices serve as a representation of the decision-makers degree of preference between a given pair of options (Ai versus Aj, for all i, j = 1, 2,…, n), as described by the matrix A = [aij] displayed in equation 1. Typically, these matrices are constructed using a scale such as the Saaty scale (Table 1). A consistent matrix is one in which the matrix elements are positive, transitive, and reciprocal (Saaty, 1977).

$$A = [a_{ij}] = \begin{bmatrix} 1 & a_{12} & . & . & a_{1j} & . & . & a_{1n} \\ \frac{1}{a_{12}} & 1 & . & . & a_{2j} & . & . & a_{2n} \\ . & & . & & & & & . \\ . & & & . & & & & . \\ \frac{1}{a_{1j}} & \frac{1}{a_{2j}} & . & . & a_{ij} & . & . & a_{in} \\ . & . & & & & . & & . \\ . & . & & & & & . & . \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & . & . & \frac{1}{a_{in}} & . & . & 1 \end{bmatrix} \quad (1)$$

Table 1. Saaty scale (Saaty, 1977)

Numerical values	Description
1	Equal importance of both aspects
3	Moderate importance of one aspect over another
5	Strong importance of one element over another
7	Very strong importance of one aspect over another
9	Extreme importance of one aspect over another
2,4,6,8	Intermediate values

Figure 2 displays the hierarchical model that has been created for Sustainable Aviation Fuel (SAF), along with its corresponding components at each level. The suggested alternative solutions are also included in the final level of the model.

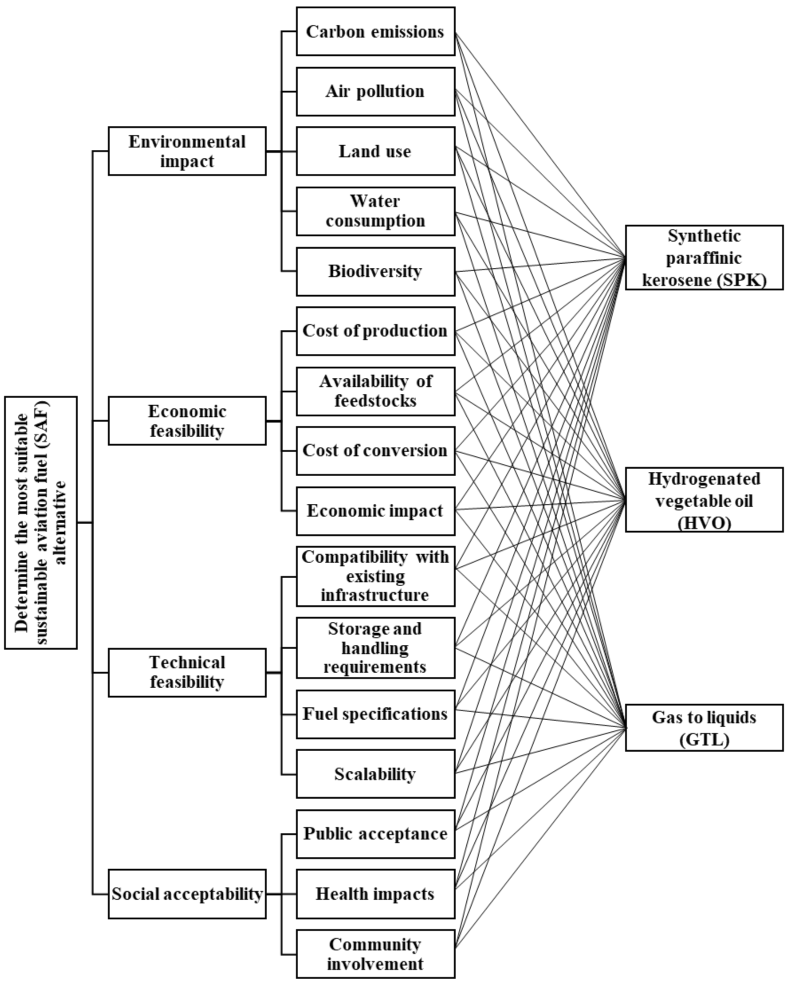

Figure 2. The SAF Hierarchy (Alharasees & Kale, 2025)

The goal of this research is to determine the most suitable sustainable aviation fuel (SAF) alternative based on a set of comprehensive criteria. The criteria are organized in a hierarchical structure as illustrated in Table 2 consisting of four main levels, each with sub-criteria:

1. Environmental Impact: This level assesses the potential environmental impact of each SAF alternative. The sub-criteria include carbon emissions, air pollution, land use, water consumption, and biodiversity. Carbon emissions are a major contributor to climate change and air pollution (Mohd Shariff et al., 2019), which can have negative impacts on human health and the environment. Land use can be a significant concern as the demand for biofuels increases, leading to deforestation and other land-use changes. Water consumption is also an important consideration, as the production of biofuels can be water-intensive. Biodiversity loss is another critical factor to consider, as land-use changes can impact habitats and ecosystems.

2. Economic Feasibility: This level evaluates the economic viability of each SAF alternative. The sub-criteria include the cost of production, availability of feedstocks, cost of conversion, and economic impact. The cost of production is a critical factor that affects the overall economic feasibility of the SAF alternative. The availability of feedstocks is also a significant consideration as it can impact the scalability of production. The cost of conversion is another important factor, as it can significantly impact the final price of the SAF. Finally, the economic impact of the SAF alternative on the market is a key consideration, as it can impact the adoption rate of the alternative fuel.

3. Technical Feasibility: This level assesses the technical feasibility of each SAF alternative. The sub-criteria include compatibility with existing infrastructure, storage and handling requirements, fuel specifications, and scalability. Compatibility with existing infrastructure is an essential consideration as it can impact the implementation of the SAF alternative. Storage and handling requirements are also crucial factors to consider, as they can impact the logistics and safety of the fuel. Fuel specifications are another important factor, as they impact the performance of the fuel in aircraft engines. Scalability is also a critical consideration as it determines the potential for large-scale production and adoption of the SAF alternative.

4. Social Acceptability: This level evaluates the social acceptability of each SAF alternative. The sub-criteria include public acceptance, health impacts, and community involvement. Public acceptance is a significant consideration, as it can impact the adoption rate of the SAF alternative. Health impacts are another important factor to consider, as they can impact the well-being of communities near SAF production facilities or airports. Finally, community involvement is also an essential consideration, as it can impact the perception and adoption of the SAF alternative in local communities.

Alternatives

In the context of the aviation industry's increasing efforts towards sustainability, the development and use of sustainable aviation fuel (SAF) have become a vital focus area for reducing carbon emissions and environmental impact. To achieve this goal, evaluating and selecting the most suitable SAF alternative based on various criteria and sub-criteria is necessary. In this regard, the following alternatives have been suggested:

Alternative 1: Synthetic Paraffinic Kerosene (SPK) Synthetic paraffinic kerosene (SPK) is a fuel produced from biomass and fossil fuels through the Fischer-Tropsch process. SPK is a promising alternative for sustainable aviation fuel due to its high energy density, low emissions, and compatibility with existing aircraft engines. The production of SPK requires the gasification of biomass or gas and coal, followed by the synthesis of hydrocarbons, refining, and blending with petroleum-based jet fuel. The production process of SPK is complex, and its cost is high compared to petroleum-based jet fuel. However, SPK has shown the potential to reduce carbon emissions and air pollution, making it a suitable candidate for evaluation in the hierarchical approach.

Alternative 2: Hydrogenated Vegetable Oil (HVO) Hydrogenated vegetable oil (HVO) is a renewable aviation fuel produced from vegetable oils through hydrogenation. The process involves heating vegetable oils with hydrogen to produce hydrocarbons that can be blended with petroleum-based jet fuel. HVO has a high energy density and a low carbon intensity, which makes it a promising alternative for sustainable aviation fuel. The production of HVO requires the availability of sufficient quantities of vegetable oils and hydrogen, and the refining process requires high-pressure hydrogenation. However, HVO has been shown to have good compatibility with existing aircraft engines, making it a suitable candidate for evaluation in the hierarchical approach.

Alternative 3: Gas to Liquids (GTL) Gas to liquids (GTL) is a process that converts natural gas into liquid hydrocarbons such as jet fuel through the Fischer-Tropsch process. GTL has a low carbon intensity and produces fewer pollutants compared to petroleum-based jet fuel. The production process of GTL involves converting natural gas into syngas through gasification and then synthesizing the syngas into hydrocarbons, refining, and blending with petroleum-based jet fuel. The production process of GTL is complex, and its cost is high compared to petroleum-based jet fuel. However, GTL has shown the potential to reduce carbon emissions and air pollution, making it a suitable candidate for evaluation in the hierarchical approach.

In conclusion, the SAF hierarchal approach provides a comprehensive and structured framework for evaluating the most suitable SAF alternative. The four levels of criteria and sub-criteria provide a detailed assessment of each alternative's environmental impact, economic feasibility, technical feasibility, and social acceptability. The suggested alternatives offer a range of options that can be further evaluated using the pairwise comparison matrices to select the most suitable SAF alternative. The next step will involve creating the PCMs based on the hierarchical model to assess and weigh all the model parameters, comprehensively evaluate the model aspects at each level, and consider all the model aspects together to eventually define the critical aspects of the constructed model.

Questionnaire: In the present study, an online survey was conducted utilizing the Analytic Hierarchy Process (AHP) methodology, involving 17 aviation specialists hailing from 12 different countries. Figure 3 visually depicts the distribution of the participating countries.

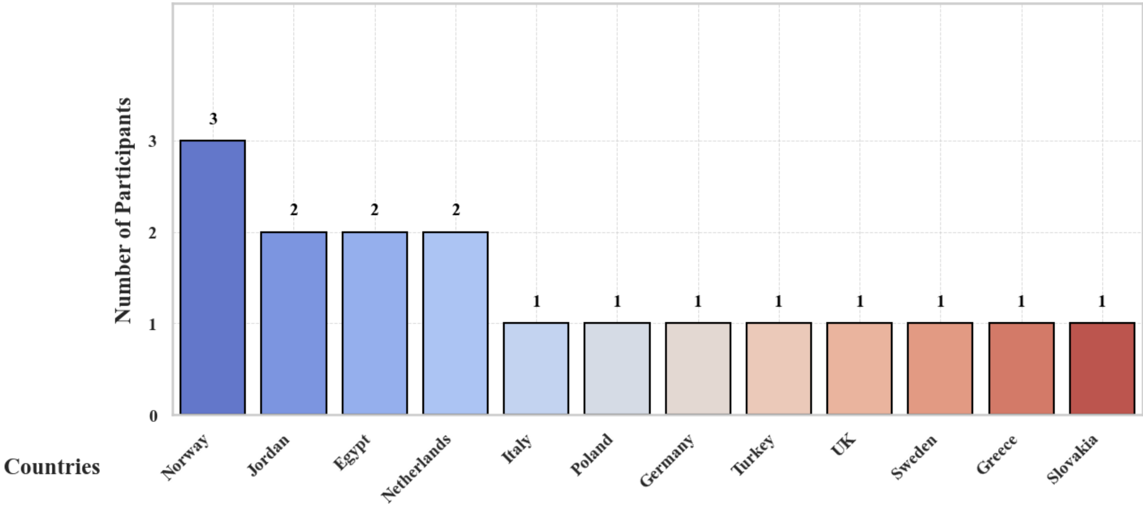

Figure 3. The distribution of the participating countries

The survey focused on evaluating the critical elements involved in the evaluation of sustainable aviation fuel (SAF) and aimed to identify the most significant challenges perceived by experts in the field. The survey utilized the job category, knowledge, and experience of the experts to consider a variety of perspectives and highlight different viewpoints of stakeholders in the aviation industry. The main objective of the survey was to quantify the challenges involved in the evaluation of SAF from the standpoint of the experts and to suggest some solutions for sustainable aviation in the future.

To ensure the accuracy of the investigation, the study was divided into two aggregated steps in the evaluation process. The first step involved categorizing the participants into five groups based on their job sector, which included pilots, air traffic controllers (ATCOs), aviation engineers, aviation managers, and aviation researchers and analysts. The demographic data for the participants are presented in Table 2. In the second step, the participants were regrouped based on their experience levels into two main groups: less experienced and experienced, as shown in Table 2 presents descriptive statistics for various demographic variables of employees in the air transportation industry, including the number of participants (N), mean age, and standard deviation of age provided for each group.

Table 2. **T**he participants' details

Variables		Total	Pilots	ATCOs	Engineers	Managers	Researchers	Experienced	Less experienced
N		17	4	3	3	3	4	4	3
Age	Mean	31	28	29	26	41	33	36	28
	SD	6	3	3	4	3	7	6	4
Gender %	Male	76%	75%	67%	100%	100%	50%	71%	80%
	Female	24%	25%	33%	0%	0%	50%	29%	20%

The age range and gender distribution of the participants are shown in Figure 4.

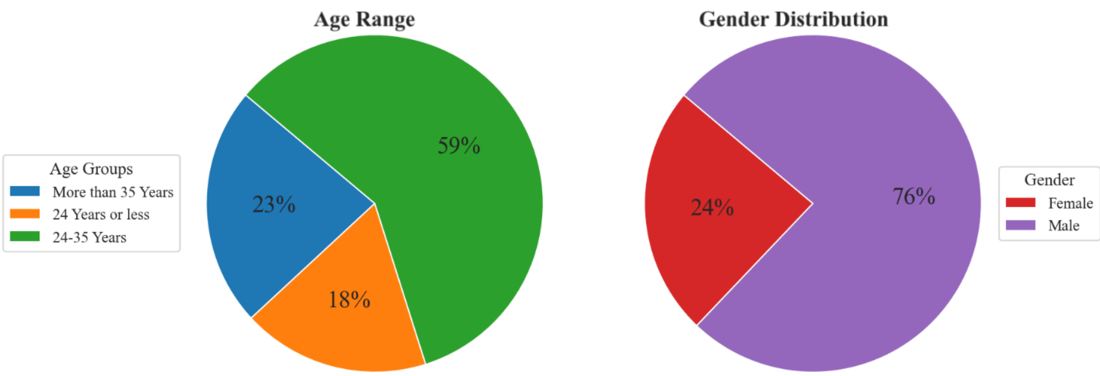

Figure 4. Age range (left) and gender distribution (right) of the participants

Pairwise comparison matrices were used to compute the matrix consistency ratio (CR) for each group, where the inconsistency in most of the experience matrices should be less than 0.1. The geometric mean for each group was then calculated to determine the relative significance of the model attributes at each level of the hierarchy.

This resulted in a single PCM for each group at each level of the hierarchy, representing the group's preferences for the associated model features. The normalization term was employed to determine the weight of each connecting element, and the final score was calculated using the aggregated eigenvector, ensuring the sum of the weights of the connected elements is 1.

RESULTS AND DISCUSSION

Upon scrutinizing the opinions of the respondents regarding the hierarchical approach of SAF evaluation, it is evident that there exist some divergences in the viewpoints of the expert groups owing to their distinct levels of expertise, occupational classifications, and comprehension of the present situation and its progression. Nevertheless, employing the Analytic Hierarchy Process (AHP) for comparing the perspectives in a pairwise manner renders a more exhaustive perspective of the sustainable aviation fuel conditions' development in the contemporary system compared to the straightforward, simplified techniques. Employing the designated methodology, the initial stage of grouping was conducted based on the job classifications, and the geometric mean was used to compute the averaged responses from each group. The weights and consistency ratios of the first level in the SAF model were calculated by each group and presented in Tables 3, 4, 5, 6, and 7.

Table 3. Pilots PCMs for the first level

PILOTs					
Criteria	Environmental impact	Economic feasibility	Technical feasibility	Social acceptability	Weights
Environmental impact	1.00	3.94	1.86	1.32	41.38%
Economic feasibility	0.25	1.00	0.64	1.11	15.09%
Technical feasibility	0.54	1.57	1.00	1.57	24.23%
Social acceptability	0.76	0.90	0.64	1.00	19.30%
CR=0.0507	Sum=				100%

Table 4. ATCOs PCMs for the first level

ATCOs					
Criteria	Environmental impact	Economic feasibility	Technical feasibility	Social acceptability	Weights
Environmental impact	1.00	4.31	1.59	2.29	46.23%
Economic feasibility	0.23	1.00	1.26	1.44	18.38%
Technical feasibility	0.63	0.79	1.00	1.26	19.97%
Social acceptability	0.44	0.69	0.79	1.00	15.42%
CR=0.0596	Sum=				100%

The first two presented tables show the weights and consistency ratios of the four criteria of the sustainable aviation fuel (SAF) model, calculated by two groups: pilots and air traffic controllers (ATCOs). the outcomes suggest that both groups share a similar view on the importance of environmental impact and technical feasibility in the development of SAF. However, the results also illustrate slightly different percentages in priorities. Pilots prioritize environmental impact and technical feasibility over economic feasibility and social acceptability, while air traffic controllers value environmental impact the most but also consider technical and economic feasibility. These differences may be related to their roles and responsibilities in the aviation industry. Pilots have a more direct impact on the environmental impact and technical feasibility of SAF, while air traffic controllers are concerned about air pollution and its effects on air traffic management.

Table 5. Aircraft engineers PCMs for the first level

ENGINEERs					
Criteria	Environmental impact	Economic feasibility	Technical feasibility	Social acceptability	Weights
Environmental impact	1.00	3.63	2.71	2.47	48.95%
Economic feasibility	0.28	1.00	2.29	1.82	22.43%
Technical feasibility	0.37	0.44	1.00	0.55	11.73%
Social acceptability	0.41	0.55	1.82	1.00	16.90%
CR=0.061	Sum=				100%

The third group of experts' outcomes in Table 6 shows that the highest weight was given to environmental impact, followed by economic feasibility, technical feasibility, and social acceptability. This indicates that engineers prioritize the environmental impact of SAF, while also considering its economic and technical feasibility, but place less emphasis on its social acceptability. The emphasis on environmental impact may be due to the engineers' technical knowledge of the effects of fuel emissions on the environment and the associated negative consequences. The lower weight given to social acceptability may indicate that engineers prioritize technical and economic feasibility over social concerns, potentially due to the perception that these are more tangible factors that can be directly addressed and solved through engineering solutions.

Table 6. Aviation managers PCMs for the first level

Management					
Criteria	Environmental impact	Economic feasibility	Technical feasibility	Social acceptability	Weights
Environmental impact	1.00	2.00	2.00	1.26	35.96%
Economic feasibility	0.50	1.00	2.15	1.00	24.65%
Technical feasibility	0.50	0.46	1.00	0.87	16.13%
Social acceptability	0.79	1.00	1.14	1.00	23.25%
CR=0.03026	Sum=				100%

Table 6 shows the criteria and weights assigned by management towards the use of SAF in the aviation industry. Environmental impact is given the highest weight, followed by economic feasibility, social acceptability, and technical feasibility. This suggests that management highly values the potential environmental benefits of using SAF, but also considers its economic feasibility and social acceptability. The relatively lower weight given to technical feasibility may indicate that management assumes the technical challenges of using SAF can be overcome with sufficient resources and research. The high weight given to social acceptability suggests that management is aware of the potential public perceptions and reactions to the use of SAF. Overall, the weights assigned by management may reflect a desire to balance environmental concerns with economic and social considerations in the decision-making process.

The Researchers group in Table 7 prioritized environmental impact as the most crucial criterion, followed by economic and technical feasibility, with social acceptability as the least important but still significant. These weightings reveal the cause-effect relationships between SAF production and the aviation system. The emphasis on environmental impact acknowledges the need to reduce harmful aviation effects, while economic and technical feasibility reflects practical limitations. Public acceptance of SAF is also considered essential for successful adoption.

Table 7. Aviation researchers PCMs for the first level

Researchers					
Criteria	Environmental impact	Economic feasibility	Technical feasibility	Social acceptability	Weights
Environmental impact	1.00	1.78	2.45	2.34	39.90%
Economic feasibility	0.56	1.00	3.03	1.28	28.58%
Technical feasibility	0.41	0.33	1.00	1.57	15.87%
Social acceptability	0.43	0.78	0.64	1.00	15.65%
CR=0.0607	Sum=				100%

Aggregating the viewpoints of the five groups of participants allows for the identification of their divergences, which could stem from dissimilar work positions and levels of proficiency. The comparison of distinct groups of participants' perspectives can enable the comprehensive assessment and appraisal of different facets of the suggested SAF hierarchical model from diverse standpoints as shown in Figure 5.

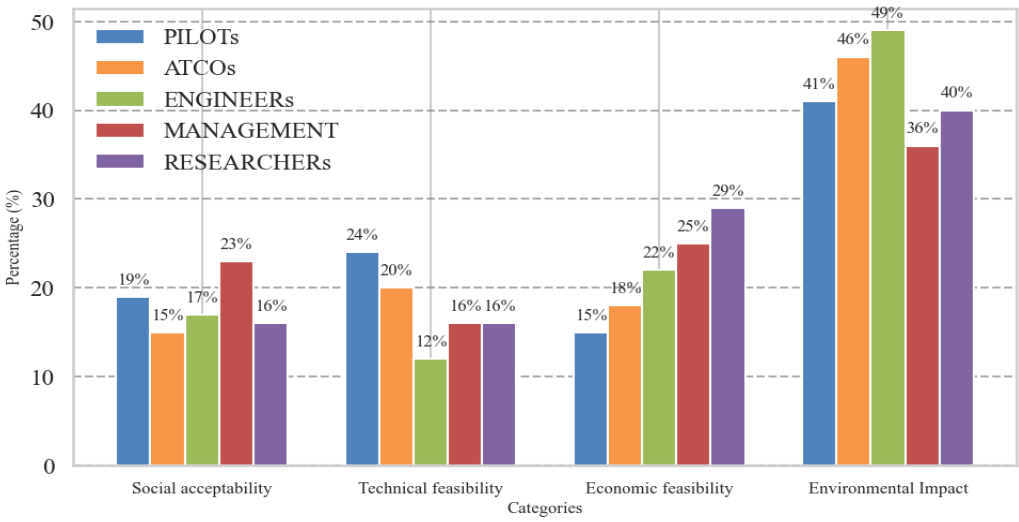

Figure 5. SAF criteria comparison - job classification based

In the second stage of aggregated evaluation, participants were regrouped into two categories based on their experience levels: a less experienced group with up to 5 years of experience (or up to 500 flight hours for pilots), and an experienced group with more than 5 years of experience (or more than 500 flight hours for pilots). The geometric mean was utilized to determine the average responses of each group. The weights and consistency ratios of the first level in the SAF model were then computed by each group and are presented in Tables 8 and 9. Table 8 shows the weight of different criteria in evaluating sustainable aviation fuels (SAF) from the perspective of less experienced aviation specialists. The environmental impact is rated as the most important criterion, followed by economic feasibility, technical feasibility, and social acceptability. The emphasis on environmental impact acknowledges the need to reduce greenhouse gas emissions and other harmful environmental effects of aviation. The weights assigned by the less experienced aviation specialists reflect a balanced and comprehensive approach to the development of sustainable aviation fuels.

Table 8. Less experienced aviation specialists PCMs for the first level

LESS EXPERIENCED					
Criteria	Environmental impact	Economic feasibility	Technical feasibility	Social acceptability	Weights
Environmental impact	1.00	1.47	1.28	1.52	31.63%
Economic feasibility	0.68	1.00	2.06	1.64	30.13%
Technical feasibility	0.78	0.49	1.00	1.45	20.89%
Social acceptability	0.66	0.61	0.69	1.00	17.36%
CR=0.0311	Sum=				100%

Table 9. Experienced aviation specialists PCMs for the first level

WELL EXPERIENCED					
Criteria	Environmental impact	Economic feasibility	Technical feasibility	Social acceptability	Weights
Environmental impact	1.00	0.77	1.49	1.51	28.68%
Economic feasibility	1.29	1.00	0.72	1.06	24.90%
Technical feasibility	0.67	1.39	1.00	1.51	26.93%
Social acceptability	0.66	0.94	0.66	1.00	19.49%
CR=0.0347	Sum=				100%

Table 9 shows that environmental impact and technical feasibility are the most critical factors for experienced aviation specialists when making decisions related to sustainable aviation fuel practices, while economic feasibility and social acceptability are of lesser importance. This finding highlights the need for the aviation industry to prioritize sustainability in its current practices and future developments. One futuristic vision toward sustainability in aviation is the adoption of Sustainable Aviation Fuels (SAF), which are considered a more sustainable alternative to traditional fossil fuels. The industry's goal is to reach carbon neutrality by 2050 (Abrantes et al., 2021), and the adoption of SAF is seen as a critical step in achieving this goal. To ensure a clear presentation of survey results and identification of critical elements in the current model from all expert perspectives, a thorough comparison of the model, including all aspects, is essential. Figure 6 comprehensively compares all aviation groups based on participant experience levels, while Figure 5 compares different participant groups based on job categories. Analyzing both figures facilitates the comparison of various criteria across different perspectives and emphasizes the most important criteria. The environmental impact criterion was found to be the most vital factor in both stages, followed by economic feasibility with some degree of variation across different groups. The focus is on identifying critical factors and their impact on the dynamic and stochastic aviation system.

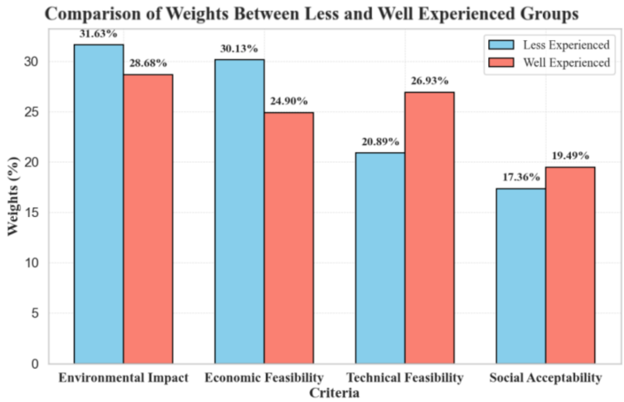

Figure 6. SAF-AHP criteria comparison experience based

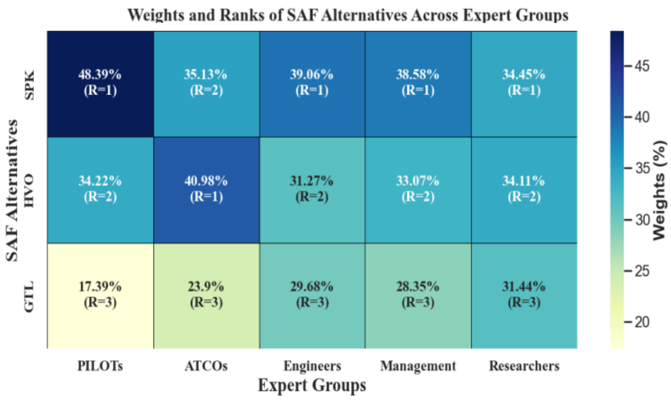

Figure 7. SAF Alternatives Heatmap

The evaluation of aviation practices based on varying levels of experience and job categories highlights the importance of prioritizing environmental impact and technical feasibility. Experienced aviation specialists tend to prioritize environmental impact and technical feasibility in their decision-making process due to their awareness of the negative impacts of sustainable aviation fuel approaches and practices on the environment and the technical aspects of aviation. Economic feasibility and social acceptability are less important to experienced aviation specialists as they can sometimes conflict with environmental and technical considerations. However, economic feasibility still holds a degree of importance as it is a vital factor in ensuring the sustainability of aviation fuel approaches and practices.The comparison of different groups based on job category and experience level provides a comprehensive understanding of the crucial elements of the current aviation system. The environmental impact criterion is the most important criterion across all groups, followed by economic feasibility. This suggests that sustainability and cost-effectiveness are crucial factors in decision-making related to sustainable aviation fuel approaches and practices. The importance of technical feasibility highlights the necessity of ensuring the safety and efficient operation of sustainable aviation fuel approaches and practices. The findings of the evaluation provide valuable insights for improving the current aviation system and moving towards a more sustainable and environmentally friendly future. Going for the Alternatives solution comparisons between the three alternatives as seen in Figure 7.

The evaluation of Sustainable Aviation Fuel (SAF) alternatives—Synthetic Paraffinic Kerosene (SPK), Hydrogenated Vegetable Oil (HVO), and Gas to Liquids (GTL)—demonstrates significant variances in preferences among aviation expert groups, driven by technological advancements and operational considerations. For instance, PILOTs assign SPK a weight of 48.39% and rank it highest (R=1), reflecting its superior performance characteristics and alignment with current engine technologies, which enhance operational efficiency and reduce emissions. In contrast, ATCOs favor HVO, giving it a weight of 40.98% and a first-place ranking (R=1), indicating a recognition of its compatibility with existing airport infrastructure and regulatory frameworks, which are crucial for seamless integration into current systems.

Engineers, Management, and Researchers show a consistent trend, ranking SPK highest and HVO second, which suggests a collective endorsement of SPK's technological merits in enhancing fuel efficiency and sustainability. The lower weights assigned to GTL across all groups, coupled with its third-place ranking, indicate a growing skepticism regarding its environmental impact and economic viability, particularly in light of advancements in cleaner fuel technologies. This structured assessment highlights the importance of aligning SAF alternatives with both technological progress and the operational realities of the aviation sector, underscoring the need for ongoing research and development to support the transition towards more sustainable aviation practices. While the study provides valuable insights into the preferences for Sustainable Aviation Fuel (SAF) across job categories and experience levels, certain limitations must be considered.

First, the sample size (17 participants) is relatively small and may not fully capture the diverse perspectives of all aviation professionals globally. A larger sample could enhance the generalizability and reliability of the findings. Additionally, the study relies on expert opinions, which, while insightful, may introduce subjective biases based on individual roles and exposure to SAF technologies. The observed differences between groups, such as pilots prioritizing technical feasibility and ATCOs focusing on infrastructure compatibility, highlight role-specific preferences.

However, these differences also underscore the need for a more integrated approach to SAF adoption that balances environmental, economic, and technical concerns. For instance, the environmental impact was consistently prioritized across groups, reflecting a consensus on sustainability's importance. Still, the comparatively lower weight assigned to social acceptability raises concerns about potential public resistance, particularly regarding feedstock competition and land use.

Moreover, while SPK emerged as the preferred alternative, its economic and technical challenges should not be underestimated. High production costs, infrastructure requirements, and dependency on technological advancements remain critical barriers. Similarly, HVO, while promising, requires significant feedstock availability, which raises questions about its scalability and impact on food security. To address these challenges, a multi-stakeholder strategy involving policymakers, industry leaders, and researchers is essential. Future studies should explore hybrid solutions that combine SAF alternatives or integrate emerging technologies, such as hydrogen and electric aviation. Additionally, longitudinal research tracking SAF adoption over time can provide a more dynamic understanding of its feasibility and impact. Overall, while this study provides a structured evaluation of SAF alternatives, it also highlights the need for continuous innovation, policy support, and cross-sector collaboration to overcome economic, technical, and social barriers.

CONCLUSIONS

The use of Sustainable Aviation Fuel (SAF) has been recognized as a promising solution for the aviation industry to achieve sustainable development which is essential for promoting sustainable tourism practices. However, the successful implementation of SAF requires comprehensive evaluation and assessment to ensure its environmental, economic, technical, and social feasibility. This study employed the Analytic Hierarchy Process (AHP) approach to evaluate and prioritize the criteria for evaluating SAF and to provide a comprehensive evaluation of SAF practices.

Based on the AHP results, the environmental impact criterion was found to be the most important criterion for evaluating SAF practices, followed by economic feasibility, technical feasibility, and social acceptability. These findings highlight the critical need for the tourism industry to adopt SAF to mitigate its environmental footprint. Furthermore, the AHP approach was able to provide a comprehensive evaluation of SAF practices by incorporating the perspectives of various groups, including experts with different levels of experience and different job categories.

The AHP approach effectively evaluates and prioritizes criteria for Sustainable Aviation Fuel (SAF) assessment, offering insights for policymakers and aviation stakeholders to enhance sustainability in both aviation practices and tourism. Adopting SAF approaches that prioritize environmental impact, economic feasibility, technical feasibility, and social acceptability is crucial for supporting sustainable tourism. Several alternative solutions to reduce aviation's environmental impact include Synthetic Paraffinic Kerosene (SPK), which blends with conventional jet fuel and significantly lowers particulate matter emissions and contrail formation. Approved for commercial aviation, SPK presents a viable SAF option for the tourism sector. Another alternative, Hydrogenated Vegetable Oil (HVO), derived from waste or non-food grade vegetable oil, also reduces particulate matter and greenhouse gas emissions, making it attractive for sustainable aviation. Gas to Liquids (GTL) is produced by converting natural gas into liquid hydrocarbons, resulting in lower emissions of nitrogen oxides, sulfur oxides, and particulate matter compared to traditional jet fuel. However, GTL's production process is energy-intensive, raising questions about its long-term sustainability.

In conclusion, the AHP approach has provided a comprehensive vision into the evaluation of SAF options, indicating various layered factors importance to consider when selecting a SAF solution. The results of this study suggest that among the evaluated SAF options, HEFA and FT-SPK are the most viable alternatives, followed by HVO and CTL. However, it is important to note that ongoing research and development in the field of SAF may lead to new and improved alternatives in the future. Therefore, continued evaluation and comparison of SAF options using rigorous and objective approaches such as AHP will be essential for promoting sustainability in the aviation industry.

Limitations

Despite the comprehensive evaluation of Sustainable Aviation Fuels (SAF) using the Analytic Hierarchy Process (AHP), this study has several limitations that should be acknowledged. The study was based on a relatively small sample of 17 aviation specialists from 12 countries. While the inclusion of participants from diverse job categories (pilots, air traffic control officers, engineers, managers, and researchers) and experience levels provides a range of perspectives, the limited sample size may constrain the generalizability of the findings. A larger, more representative sample could improve the reliability and robustness of the results, particularly for drawing conclusions applicable to the global aviation industry.

The AHP methodology heavily relies on subjective expert evaluations, which may introduce biases influenced by individual roles, experiences, and perceptions. While the geometric mean aggregation method was used to minimize these biases, the inherent subjectivity of the pairwise comparison matrices (PCMs) cannot be entirely eliminated. Experts' exposure to specific SAF technologies or regional aviation policies may also have shaped their preferences, potentially limiting the objectivity of the results. The study evaluated three primary SAF alternatives - Synthetic Paraffinic Kerosene (SPK), Hydrogenated Vegetable Oil (HVO), and Gas-to-Liquids (GTL). While these are recognized as promising options, emerging SAF technologies, such as power-to-liquid (PtL) fuels, bioethanol-based fuels, or hydrogen-powered aviation, were not considered. This limited scope may restrict the study's applicability as new technologies are developed and adopted in the aviation sector. The study does not explicitly address the influence of regional variations in SAF production, policy incentives, and infrastructure readiness. Differences in government regulations, availability of feedstocks, and economic subsidies could significantly impact the adoption and feasibility of SAF alternatives. Future studies could integrate a regional analysis to capture these contextual dynamics more effectively.

While social acceptability was included as a criterion, the study primarily focused on expert opinions, neglecting broader public perceptions of SAF. Given the growing importance of societal acceptance in the transition to sustainable fuels, future research should incorporate public attitudes, concerns about land use, and potential resistance to SAF adoption. The AHP method, though rigorous, provides a static assessment of SAF alternatives at a specific point in time.

However, technological advancements, policy changes, and evolving market conditions can rapidly influence the viability and preference for SAF options. A longitudinal approach or dynamic decision-making models could better capture these changes over time. The study highlights environmental and economic feasibility as critical factors but does not delve deeply into the trade-offs between these criteria.

For example, the production of SAF alternatives, such as HVO and GTL, involves processes that may indirectly contribute to environmental issues like land use changes, biodiversity loss, and water consumption. Further analysis of such trade-offs is necessary to provide a holistic understanding of SAF sustainability.

While the findings of this study offer valuable insights into SAF evaluation and preferences, these limitations underscore the need for future research to address the identified gaps. Expanding the sample size, incorporating emerging SAF technologies, considering regional and public perspectives, and adopting dynamic frameworks will strengthen the understanding of SAF adoption and its role in achieving aviation sustainability.

Nomenclature: SAF: sustainable aviation fuel; AHP: Analytical Hierarchy Process; MCDM: Multiple Criteria Decision Making; PCM: Pairwise comparison matrix; ATCOs: Air traffic controllers; CR: Consistency Ratio; SPK: Synthetic Paraffinic Kerosene; HVO: Hydrogenated Vegetable Oil; GTL: Gas to Liquids

Author Contributions: Conceptualization, O.A., D.R. and U.K.; methodology, U.K., O.A., D.R. and A.M.; formal analysis, O.A. and U.K; data curation, O.A. and D.R.; writing - original draft preparation, A.M., O.A. and U.K.; writing - review and editing, O.A. and U.K.; visualization, D.R. and O.A.; supervision, D.R and U.K.; project administration, U.K All authors have read and agreed to the published version of the manuscript.

Funding: Not applicable.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study may be obtained on request from the corresponding author.

Acknowledgments: "Project No. 2022-2.1.1-NL-2022-00012 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the National Laboratories funding scheme".

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

Abrantes, I., Ferreira, A. F., Silva, A., & Costa, M. (2021). Sustainable aviation fuels and imminent technologies-CO2 emissions evolution towards 2050. *Journal of Cleaner Production*, 313, 127937. https://doi.org/10.1016/J.JCLEPRO.2021.127937

Ahmad, S., Ouenniche, J., Greening, P., Kolosz, B., Andresen, J., Maroto-Valer, M., & Xu, B. (2019). A Value Tree For Multi-Criteria Evaluation of Sustainable Aviation Fuels. *International Conference on Applied Energy*, Västerås, Sweden, Paper ID: 806.

Alharasees, O., Kale, U., Rohacs, J., & Rohacs, D. (2024a). Enhancing sustainability in aviation: AHP analysis and smart energy concept'. I*nternational Journal of Global Warming,* 33(1), 69–91. https://doi.org/10.1504/IJGW.2024.138104

Alharasees, O., Kale, U., Rohacs, J., Rohacs, D., Eva, M. A., & Boros, A. (2024b). Green building energy: Patents analysis and analytical hierarchy process evaluation. *Heliyon,* 10(8), e29442. https://doi.org/10.1016/J.HELIYON.2024.E29442

Alharasees, O., Abdalla, M. S. M., & Kale, U. (2022). Analysis of Human Factors Analysis and Classification System (HFACS) of UAV Operators. *New Trends in Aviation Development* (NTAD),10–14. https://doi.org/10.1109/NTAD57912.2022.10013492.

Alharasees, O., & Kale, U. (2022). Air Transport Projects Quality Assessments by Analytical Hierarchy Process (AHP), *Repüléstudományi Közlemények,* 34(2), 73–82. https://doi.org/10.32560/rk.2022.2.6

Alharasees, O., & Kale, U. (2023). Applying AHP for supplier selection in aviation: a multi-criteria decision-making approach, *International Journal of Sustainable Aviation,* 9(4), 293–313. https://doi.org/10.1504/IJSA.2023.134344

Alharasees, O., & Kale, U. (2025). Selection of Sustainable Aviation Fuels: An Expert-Based Comparative Approach. In *Energy and Sustainable Aviation Fuels Solutions. International Symposium On Sustainable Aviation.* 43-49, Springer, Cham. https://doi.org/10. 1007/978-3-031-70694-3_9

Alharasees, O., & Kale, U. (2024). Aviation Operators' Total Loads Analysis by Multi-Criteria Decision-Making, *Journal of Air Transport Management,* 118, p. 102596. https://doi.org/10.1016/J.JAIRTRAMAN.2024.102596

Anderson, B. J., Mueller, D. W., Hoard, S. A., Sanders, C. M., & Rijkhoff, S. A. (2022). Social science applications in sustainable aviation biofuels research: Opportunities, challenges, and advancements. *Frontiers in Energy Research*, *9*, 771849. https://doi.org/10.3389/FENRG.2021.771849/BIBTEX

Atshan, N. A., Jamaludin, H., Seng Tong, C., Abrrow, H. A., & Abbas, S. (2024). Does Environmental, Social And Governance Have An Impact On How Green Hotels Are? Purchase Intention As A Moderator Variable. Opinions Of A Sample Of Hotel Customers In Iraq. *Geojournal of Tourism and Geosites*, 56(4), 1762–1772. https://doi.org/10.30892/gtg.56431-1345

Bergero, C., Gosnell, G., Gielen, D., Kang, S., Bazilian, M., & Davis, S. J. (2023). Pathways to net-zero emissions from aviation. *Nature Sustainability*, *6*(4), 404-414. https://doi.org/10.1038/s41893-022-01046-9

Cabrera, E., & de Sousa, J. M. M. (2022). Use of Sustainable Fuels in Aviation - A Review. Energies, 15(7), 2440. https://doi.org/10.3390/en15072440

Chong, J. W., Chemmangattuvalappil, N. G., & Thangalazhy-Gopakumar, S. (2023). Aviation Biofuels: Conversion Routes and Challenges. *Sustainable Technologies for the Oil Palm Industry*, 33–85. https://doi.org/10.1007/978-981-19-4847-3_2

Al Dein, E., Fahmawee, A. L., & Jawabreh, O. (2023). Sustainability of Green Tourism By International Tourists and its Impact on Green Environmental Achievement: Petra Heritage, Jordan. *Geojournal of Tourism and Geosites*, 46(1), 27–36. https://doi.org/10.30892/gtg.46103-997

Detsios, N., Theodoraki, S., Maragoudaki, L., Atsonios, K., Grammelis, P., & Orfanoudakis, N. G. (2023). Recent advances on alternative aviation fuels/pathways: A critical review. *Energies*, *16*(4), 1904. https://doi.org/10.3390/EN16041904

Esparza-Huamanchumo, R. M., Botezan, I., Sanchez-Jimenez, R., & Villalba-Condori, K. O. (2024). Ecotourism, sustainable tourism and nature based tourism: an analysis of emerging fields in tourism scientific literature. *Geojournal of Tourism and Geosites*, *54*, 953-966. https://doi.org/10.30892/gtg.542spl19-1270

Fanni, Z., & Rezazadeh, S. M. (2018). Analysing The Urban Environment Sustainability Influenced By Tourism In Iran (District 1 Of Tehran Metropolis). *Geojournal of Tourism and Geosites*, 23 (3), 719–730. https://doi.org/10.30892/gtg.23308-322

Hileman, J. I., & Stratton, R. W. (2014). Alternative jet fuel feasibility. *Transport Policy*, 34, 52–62. https://doi.org/10.1016/J.TRANPOL.2014.02.018

IATA (2023) Quarterly Air Transport Chartbook IATA Sustainability & Economics Q1 2023. pp. 34.

Kantenbacher, J., Hanna, P., Cohen, S., Miller, G., & Scarles, C. (2018). Public attitudes about climate policy options for aviation. *Environmental Science & Policy*, 81, 46-53. https://doi.org/10.1016/j.envsci.2017.12.012

Kuqi, B. (2018). Theoretical approach concerning the development of sustainable tourism as tourist destination in Kosovo. *GeoJournal of Tourism and Geosites*, 22 (2), 489–496. https://doi.org/10.30892/gtg.22218-305

Kyriakaki, A., & Kleinaki, M. (2021). Planning a Sustainable Tourism Destination Focusing on Tourists Expectations, Perceptions And Experiences. *Geojournal of Tourism and Geosites*, 40(1), 225–231. https://doi.org/10.30892/GTG.40127-823

Martinez-Valencia, L., Garcia-Perez, M., & Wolcott, M. P. (2021). Supply chain configuration of sustainable aviation fuel: Review, challenges, and pathways for including environmental and social benefits. *Renewable and Sustainable Energy Reviews,* 152, p. 111680. https://doi.org/10.1016/J.RSER.2021.111680

Mofijur, M., Ahmed, S. F., Rony, Z. I., Khoo, K. S., Chowdhury, A. A., Kalam, M. A., Le, V. G. I., Badruddin, I. A., & Khan, T. Y. (2023). Screening of non-edible (second-generation) feedstocks for the production of sustainable aviation fuel. *Fuel*, *331*, p. 125879. https://doi.org/10.1016/J.FUEL.2022.125879

Mohd Shariff, N., Zainol Abidin, A., & Mohamed, A. E. (2019). Tourism Event: Perceptions On The Critical Indicators Of Climate Variability And Change In Malaysia. *GeoJournal of Tourism and Geosites*, 24 (1), 39–47. https://doi.org/10.30892/gtg.24104-341

Monte, D. M., del, Cruz, P. L., & Dufour, J. (2022). SAF production from cameline oil hydrotreatment: A technoeconomic assessment of alternative process configurations. *Fuel,* 324, p. 124602. https://doi.org/10.1016/J.FUEL.2022.124602

Montoya Sánchez, N., Link, F., Chauhan, G., Halmenschlager, C., El-Sayed, H. E., Sehdev, R., Lehoux, R., & de Klerk, A. (2022). Conversion of waste to sustainable aviation fuel via Fischer–Tropsch synthesis: Front-end design decisions. *Energy Science & Engineering*, *10*(5), 1763-1789. https://doi.org/10.1002/ese3.1072

O'malley, J., Pavlenko, N., & Searle, S. (2021). Estimating sustainable aviation fuel feedstock availability to meet growing European Union demand. *International Council on Clean Transportation:* Berlin, Germany.

Ram, V., & Salkuti, S. R. (2023). An Overview of Major Synthetic Fuels. *Energies*, 16(6), 2834. https://doi.org/10.3390/EN16062834

Refaat, S. A., & Arafa, H. F. (2022). Investigating The Effect of Covid-19 Global Travel Restrictions on Tourists Travel Behavior, Habits and Intentions "Applied Study on Saudi Tourists". *Geojournal of Tourism and Geosites*, 40(1), 49–55. https://doi.org/10.30892/GTG.40105-801

Saaty, T. (1994). *Fundamentals of Decision Making and Priority Theory with the AHP*. RWS Publications, Pittsburgh, PA, U.S.A. 29(1).

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15(3) 234-281. https://doi.org/10.1016/0022-2496(77)90033-5

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research,* 48(1). Available at: https://doi.org/10.1016/0377-2217(90)90057-I

Schmidt, P., Batteiger, V., Roth, A., Weindorf, W., & Raksha, T. (2018). Power‐to‐liquids as renewable fuel option for aviation: a review. *Chemie Ingenieur Technik*, *90*(1-2), 127-140. https://doi.org/10.1002/CITE.201700129

Shahabuddin, M., Alam, M. T., Krishna, B. B., Bhaskar, T., & Perkins, G. (2020). A review on the production of renewable aviation fuels from the gasification of biomass and residual wastes. *Bioresource Technology*, *312*, 123596. https://doi.org/10.1016/J.BIORTECH.2020.123596

Shahriar, M. F., & Khanal, A. (2022). The current techno-economic, environmental, policy status and perspectives of sustainable aviation fuel (SAF). *Fuel*, 325, p. 124905. https://doi.org/10.1016/J.FUEL.2022.124905

Sutiksno, D. U., Souisa, W., Purnomo, A., Buyang, C. G., & Lau, E. (2024). The Evolution of Ecotourism on Geoheritage in Scientific Research: A Bibliometric Analysis. *GeoJournal of Tourism and Geosites*, 52(1), 239-249. https://doi.org/10.30892/gtg.52123-1200

Tanzil, A. H., Brandt, K., Wolcott, M., Zhang, X., & Garcia-Perez, M. (2021). Strategic assessment of sustainable aviation fuel production technologies: Yield improvement and cost reduction opportunities. *Biomass and Bioenergy*, *145*, 105942. https://doi.org/10.1016/J.BIOMBIOE.2020.105942

World Tourism Organization (2024). International tourism to reach pre-pandemic levels in 2024. (Accessed: 3 November 2024). www.unwto.org/market-intelligence.

Qasem, N. A., Mourad, A., Abderrahmane, A., Said, Z., Younis, O., Guedri, K., & Kolsi, L. (2024). A recent review of aviation fuels and sustainable aviation fuels. *Journal of Thermal Analysis and Calorimetry*, 149(10), 4287-4312. https://doi.org/10.1007/s10973-024-13027-5

Article history: Received: 05.11.2024 Revised: 03.03.2025 Accepted: 01.04.2025 Available online: 07.05.2025