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Policy Paper

Sustainable Bioavtur Development Strategy in Indonesia

Moristanto[1]*, Nastiti Siswi Indrasti[2], Dwi Setyaningsih[3], M. Indra Al Irsyad[4] and Yanto Rochmayanto[5]

[1,2,3]*Agro Industri Engineering, IPB University, Bogor, Indonesia*
[4,5]*National Research and Innovation Agency, Jakarta, Indonesia*

***Corresponding author**: masmoristanto@apps.ipb.ac.id

Abstract

Reducing emissions in the aviation sector in Indonesia is in line with international decarbonization efforts. This study aims to assess the potential for sustainable bioavtur development in Indonesia, to project future demand and emission reduction requirements, and to identify priority feedstocks and process technologies. Aviation fuel consumption is projected to grow from 4.9 million kilolitres in 2024 to 12.5 million kilolitres in 2060, while the sector must move from 1.9 million tons of CO2e in 2024 to a reduction of 25.6 million tons of CO2e in 2060, in line with the global target of an 85% cut from 2019 levels and carbon-neutral growth in international aviation from 2027. The study combines demand and emission projections, simulation of raw material availability, and multi-criteria decision analysis (MCDA) to rank feedstocks and technologies. The results show that crude palm oil, used cooking oil, and the organic fraction of municipal solid waste, partly generated by the free nutritious meals programme, together with HEFA and FT processes, are the current priorities for development. A series of policies need to be promoted to support bioavtur production, including raw material security, decarbonization technology options, ease of investment, incentive support to achieve economic viability, and balanced information dissemination.

Keywords: decarbonization; bioavtur; emissions; production; and policy.

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Fax: +62 21 31928281
E-mail: journal.pusbindiklatren@bappenas.go.id

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1. Introduction

Bioavtur is an aviation fuel produced with environmental considerations, using sustainable resources and having a low impact on greenhouse gas emissions (ICAO, 2022). Under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Eligible Fuel (CEF), Sustainable Bioavtur is the most feasible alternative fuel to be developed in Indonesia. It is a type of fuel produced from renewable resources and has a lower environmental impact than conventional fossil-based aviation fuel (Ministry of Energy and Mineral Resources, 2025). It is designed to reduce the carbon footprint and greenhouse gas emissions in the aviation industry. A sustainable bioavtur is designated to meet ASTM standards. ASTM D7566 establishes stringent specifications for blending non-petroleum components with standard petroleum-based jet fuels certified to ASTM D1655 (ICAO, 2022).

The demand for sustainable bioavtur is a function of the demand for aviation fuel and the biofuel mandate in the aviation industry (Thunder Said Energy, 2023). Aviation fuel demand is derived from the aviation industry's needs, driven by the number of air travel and the number of air passengers. Therefore, projections of aviation fuel demand can be predicted from projections of future air passenger numbers. Meanwhile, the biofuel mandate in the aviation industry should also be a key reference for projecting the need for sustainable bioavtur, as demand for sustainable bioavtur cannot grow independently without regulatory intervention. The current price of sustainable bioavtur is still around 1.5 to 6 times higher than that of aviation fuel, requiring support for the aviation industry to transition from aviation fuel to sustainable bioavtur (European Union Aviation Safety Agency, 2022).

The Cilacap Green Refinery is capable of producing Bioavtur with a capacity of 9,000 barrels per day (bpd) through co-processing (Pertamina, 2025). PT Kilang Pertamina Internasional aims to begin producing 100% palm kernel oil-based aviation fuel (avtur), or 100% bioavtur, at the Cilacap Refinery in 2026. The Cilacap Green Refinery Phase 2 project also aims to increase the processing capacity of hydrotreated vegetable oil (HVO) from the current 3,000 bpd to 6,000 bpd (Pertamina, 2025). Therefore, a sustainable supply of bioavtur with 100% vegetable oil as the raw material is expected to emerge in 2026, amounting to 6,000 bpd, or approximately 260,000 kL per year.

To date, studies comprehensively analyzing the development of bioavtur in Indonesia remain limited. Existing studies generally estimate the potential for bioavtur production from agricultural, municipal, and plantation waste (Inayah et al., 2026), and address issues related to sustainable aviation, including investigations into sustainable aviation fuels, their production processes, and their use in aviation. Currently, there are no concrete efforts or activities to reduce emissions in the aviation sector. This means the aviation sector must reduce emissions by 25.6 million tons of CO2e by 2060. Our study aims to address this research gap. Moreover, the novelty of this paper is in the form of Strategic Practical Novelty's novelty lies in its strategic practical contribution to policies, regulations, and development strategies based on scientific research. To date, the implementation of mandatory bioavtur in Indonesia has not been implemented.

The purpose of this study is to provide an overview of the potential for bioavtur development, to show the extent to which bioavtur development contributes to and improves aviation fuel resilience in Indonesia, and to provide direction on how industry and government synergy can work together in developing the bioavtur industry as a sustainable fuel in Indonesia for aviation. The methodology used in this study included a literature review, interviews, and field visits to the refinery owned by PT Pertamina (Persero), which has developed and produced bioavtur at a pilot-plant scale in Cilacap. To provide an initial overview of the suitability of raw materials and technology, an initial selection of raw materials can be made using the multi-criteria decision analysis (MCDA) method. The MCDA method assesses the priority order of alternatives by considering certain factors as constraints in the selection (Kigozy and Aboyade, 2014). This method is widely used for decision-making and can be applied at varying levels of detail.

2. Methods

The methodology used in this study included a literature review, interviews, and field visits to the refinery owned by PT Pertamina (Persero), which has developed and produced bioavtur at a pilot-plant scale in Cilacap. Test result data, including coprocessing production testing, static testing, flight testing, and the results of running simulations of licensed platforms such as Nexchem, which is known as the latest developments in bioavtur, policies, and the current conditions of the aviation industry. Interviews were conducted with fuel suppliers such as Pertamina Indonesia Refinery, Tripatra, and Shell Indonesia through in-depth interviews, online discussions, and audiences. A field visit was conducted at the Cilacap Refinery, which operates through coprocessing and produces bioavtur from a variety of oil- and fat-based raw materials. The Projections of aviation fuel demand can be predicted from projections of future air passenger numbers, a function of the demand for aviation fuel and the biofuel mandate in the aviation industry (Coordinating Minister for Maritime Affairs and Investment, 2024). To provide an initial overview of the suitability of raw materials and technology, an initial selection of raw materials can be made using the multi-criteria decision analysis (MCDA) method. The MCDA method is used to assess the priority order of various alternatives by considering certain factors (as constraints in the selection). This method is widely used for decision-making, with varying levels of detail. The MCDA method used was MCDA-SMARTER (Simple Multi-Attribute Rating Technique Extended to Ranking), which is widely used for initial screening of alternatives and involves independent assessment criteria. In the MCDA-SMARTER method, the alternatives being reviewed are scored based on the specified criteria. The alternative with the highest conformance to the criteria receives a score of 10 (highest), while very low conformance receives 1 (lowest). The criteria are formulated qualitatively, designed to be quantifiable, and then used in the score calculation. In this method, the selected criteria are also assigned different weights. This is intended to highlight the priority of one criterion over another. Weighting is done systematically using the rank of centroid (ROC) method (Barron and Barrett, 1996). This method is widely used for decision-making, with varying levels of detail. The Projections of aviation fuel demand can be predicted from projections of future air passenger numbers, a function of the demand for aviation fuel and the biofuel mandate in the aviation industry.

3. Results and Discussions

3.1 Sustainable Bioavtur Demand in The Future

The demand for sustainable bioavtur depends of aviation fuel demand and the biofuel mandate in the aviation industry. Aviation fuel demand is derived from the aviation industry's needs, driven by the number of air travel and the number of air passengers. Therefore, projections of aviation fuel demand can be predicted from projections of future air passenger numbers. Meanwhile, the biofuel mandate in the aviation industry should also be a key reference for projecting the need for sustainable bioavtur, as demand for sustainable bioavtur cannot grow independently without regulatory intervention. The current price of sustainable bioavtur is still around 1.5 to 6 times higher than that of aviation fuel, requiring support for the aviation industry to transition from aviation fuel to sustainable bioavtur (European Union Aviation Safety Agency, 2022).

The relationship between the number of air passengers and the demand for aviation fuel in Indonesia can be seen in Figure 1 below.

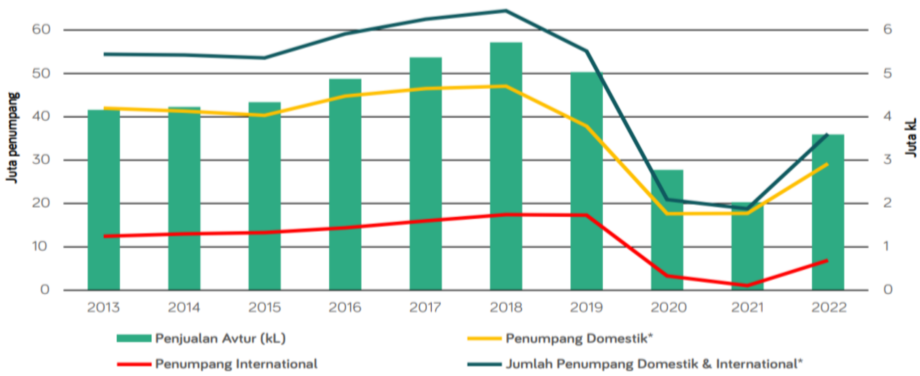

Figure 1. Aviation Fuel Demand and Air Passenger Numbers at Five Major Indonesian Airports

According to data on air passenger numbers at five major Indonesian airports, both domestic and international, as shown in Figure 1, passenger numbers increased from 86.82 million in 2013 to 113.14 million in 2018, before declining to a low of 31.33 million in 2021 due to the COVID-19 pandemic. This dynamic in air passenger numbers is also accompanied by a consistent trend in aviation fuel sales in Indonesia. In 2013, aviation fuel sales in Indonesia reached 4.16 million kL, peaking at 5.72 million kL in 2018 before declining to a low of 2.03 million kL in 2021. Both air passenger numbers and aviation fuel sales rebounded in 2022 as public mobility recovered following the COVID-19 pandemic. The relationship between air passenger numbers in Indonesia and aviation fuel sales can also be seen in the scatterplot in Figure 2 below.

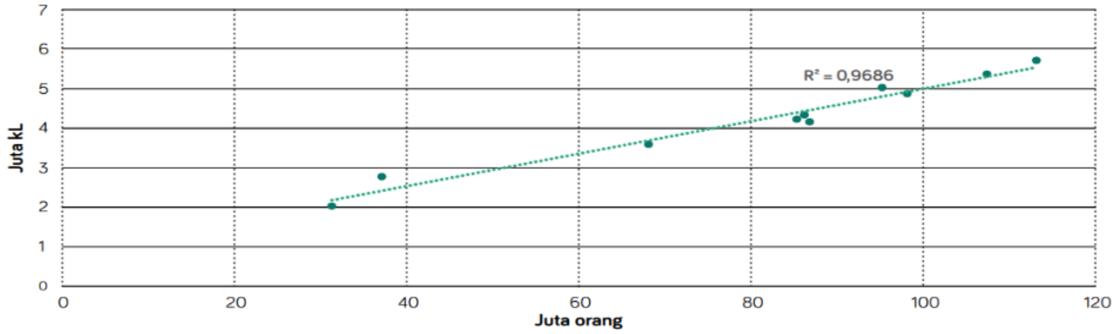

Figure 2. Relationship between Passenger Numbers and Aviation Fuel Demand (2013-2022)

Figure 2 shows that aviation fuel sales have a positive linear relationship with the number of air passengers in Indonesia, with an R2 value of 0.9686. This indicates that the number of passengers explains 96.86% of aviation fuel sales in Indonesia. The scatterplot in Figure 2 also provides a mathematical model to predict the linear relationship between air passenger numbers and aviation fuel demand, using the following equation:

Aviation Fuel (kL) = 891,173 + 41,054 x Number of Passengers

Once it is known that aviation fuel demand is influenced by the number of air passengers, the next step is to determine the projected growth in the number of air passengers in Indonesia. References containing projections of the number of air passengers in Indonesia adjusted for the COVID-19 pandemic are still quite limited. Meanwhile, Airport Council International (2023) predicts that the number of passengers in 2024 will match the pre-pandemic level in 2019 as shown in Figure 3 below.

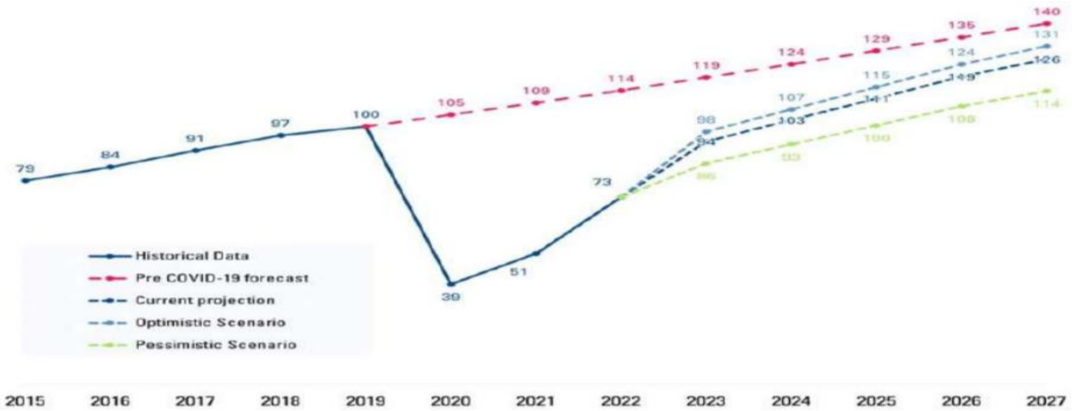

Figure 3. Projected Air Passenger Numbers Based on Conditions Before the COVID-19 Pandemic
Source: (Airport Council International, 2023)

Using 2019 passenger numbers as a baseline, air passenger numbers are predicted to reach pre-COVID-19 levels in 2024, with a coefficient of 1.03. Air passenger numbers are predicted to continue to increase, following the pre-COVID-19 trajectory. Other references also indicate that global aviation fuel demand will continue to increase with positive growth until 2050, reaching 18 million barrels per day (Thunder Said Energy, 2023).

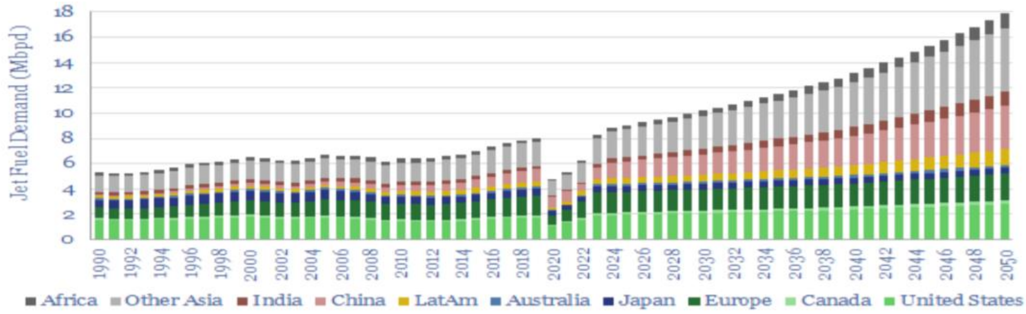

Figure 4. Projected Global Aviation Fuel Demand to 2050
Source: Thunder Said Energy, 2023

However, when projecting aviation fuel demand based on air passenger numbers, it's important to note that several supply-side factors can influence the relationship between passenger numbers and aviation fuel demand in Indonesia. These include the availability of operational aircraft by airlines, which is currently below demand, and high ticket prices, which can impact air passenger numbers. Projected air passenger numbers and aviation fuel demand in Indonesia are shown in Figure 5 below.

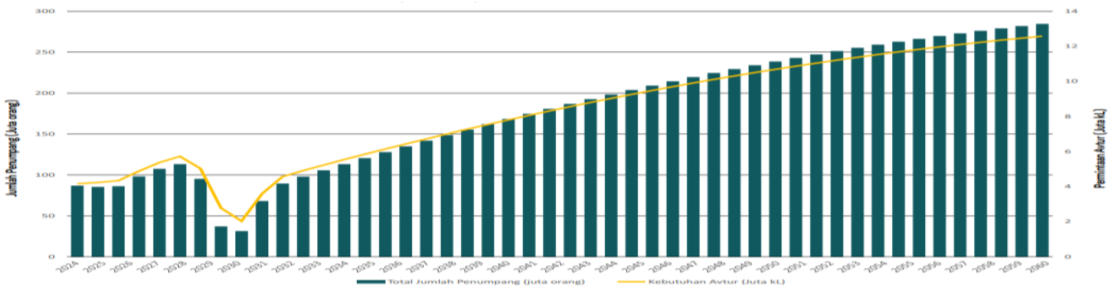

Figure 5. Projected Passenger Numbers and Aviation Fuel Demand in the Aviation Industry

Based on the projected passenger numbers and aviation fuel demand in Indonesia shown in the figure, air passengers are projected to reach 285 million, with aviation fuel demand estimated at 12.5 million kL in 2060. The next step in projecting sustainable bioavtur demand is to determine the scenario mandating biofuel use in the aviation industry. Based on Minister of Energy and Mineral Resources Regulation No. 12 of 2015, the mandated biofuel utilization in the aviation industry is 2% in 2016, 3% in 2020, and 5% in 2025. Assuming this biofuel mandate in the aviation industry as a sustainable bioavtur demand, the sustainable bioavtur demand in Indonesia can be projected until 2060, as shown in Figure 6 below.

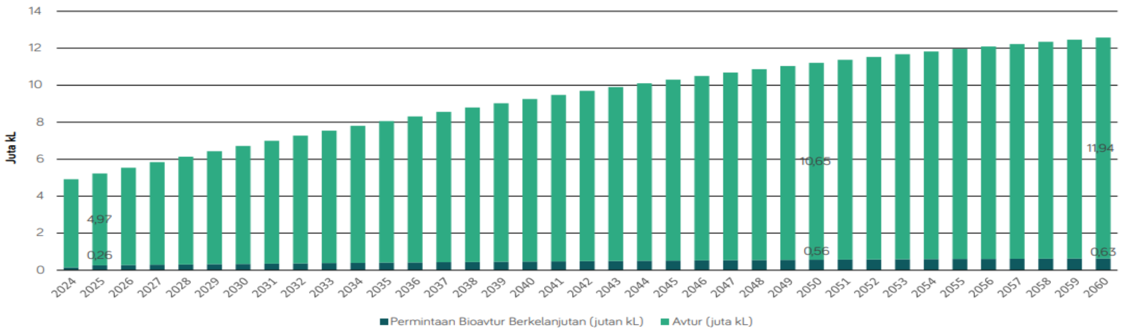

Figure 6. Projected Sustainable Bioavtur Demand: 5% Biofuel Utilization Mandate in 2025

According to Figure 7, the demand for sustainable bioavtur will reach 260,000 kL in 2025 when the biofuel utilization mandate reaches 5%. This figure will continue to increase to 630,000 kL in 2060. However, adjustments to the biofuel utilization mandate in the aviation industry are necessary, considering that as of 2023, sustainable bioavtur production in Indonesia is still in the trial phase, with a 2.4% ratio (J2.4) produced through coprocessing at Pertamina refineries. A stand-alone bioavtur refinery is expected to begin production in 2026 with a capacity of 260,000 kL at RU IV Cilacap, using HEFA technology and used cooking oil (UCO) as feedstock.

On the other hand, there is a commitment from ICAO to reset the baseline of CORSIA to 85% of 2019 emissions. CORSIA mandates sectoral carbon-neutral growth in the international aviation industry starting in 2027. Based on this mandate, the carbon reduction target is the difference between the current year's carbon emissions and 85% of the country's aviation sector carbon emissions in 2019.

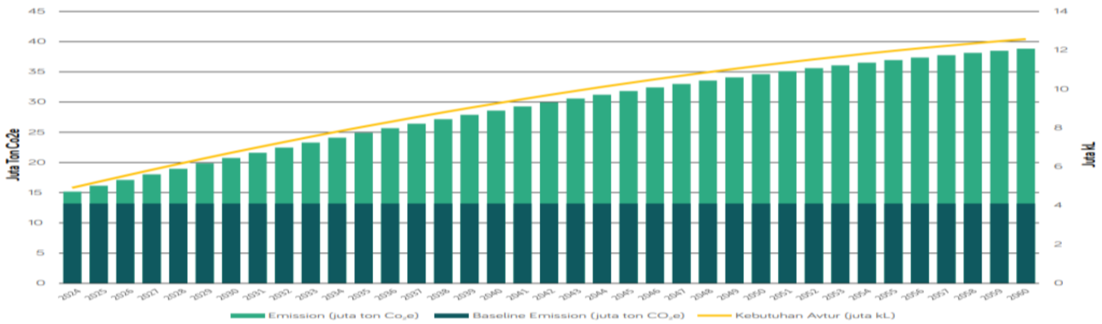

Figure 7. Carbon Emission Projections and Emission Baseline to 2060

Based on Indonesia's 2019 aviation fuel consumption of 5.04 million kL and the CORSIA jet fuel baseline emission of 89 gCO2e/MJ, Indonesia's baseline carbon emissions are 13.2 million tons of CO2e. Meanwhile, based on projections of aviation fuel consumption in Indonesia, the annual carbon emissions generated by the Indonesian aviation industry are projected to range from 15.17 million tons of CO2e in 2024 to 38.83 million tons of CO2e in 2060. With the established baseline, the target is to reduce carbon emissions from 15.17 million tons of CO2e in 2024 to 25.62 million tons of CO2e in 2060.

3.2 Sustainable Supply of Bioavtur in The Future

Currently, Pertamina has conducted a co-processing trial between Refined Bleached Deodorized Palm Kernel Oil (RBDPKO) and kerosene at the TDHT RU IV Cilacap unit using Hydroprocessed Esters and Fatty Acid (HEFA) technology to produce bioavtur. However, because Pertamina has limited equipment, the maximum mixing is still 2.4%, so it can only produce Bioavtur J2.4. The next step is the Development of the Cilacap Green Refinery (Phase-2) with more varied raw materials that can be based on waste such as Crude palm oil, used cooking oil, and organic phase municipal solid waste, one of which comes from the free nutritious meals program, Palm Oil Mill Effluent (POME), or Palm Acid Oil (PAO).

The Cilacap Refinery Green Refinery is capable of producing Bioavtur with a capacity of 9,000 barrels per day (bpd). PT Kilang Pertamina Internasional targets to begin producing aviation fuel (avtur) made from 100% palm kernel oil, or 100% bioavtur, at its Cilacap Refinery in 2026. The Cilacap Refinery's Green Refinery Phase 2 project also aims to increase the processing capacity of hydrotreated vegetable oil (HVO) from the current 3,000 bpd to 6,000 bpd. Therefore, a sustainable supply of bioavtur made from 100% vegetable oil will emerge only in 2026, reaching 6,000 bpd, or approximately 260,000 kL per year.

In more detail, the bioavtur supply strategy, based on this study, for the period 2024 to 2026, will utilize J2.4 fuel, currently produced at Pertamina's Refinery Unit IV in Cilacap. In 2027, the production of neat SAF J100 from Used Cooking Oil (UCO) began with a capacity of 238,000 kL per year. Furthermore, the establishment of a neat SAF J100 green refinery from UCO with of capacity of 238,000 kL was also established in 2029 and 2031. In order to pursue a greater CO2 reduction target, this study recommends the construction of a green refinery SAF J100 from UCO of 800,000 kL in 2033. In 2033, the target reduction in CO2 emissions of 1,160,424 tons of CO2e can be offset by the existing UCO-based bioavtur production. In 2033, the proposed mix is 15.4%. In 2038, another UCO SAF plant with a capacity of 238,000 kL and a target mix of 20% will be established. Biomass-based SAF production is predicted to begin in 2040 with a capacity of 238,000 kL. Furthermore, the process of increasing biomass-based SAF production will increase through the establishment of new plants in 2043 (238,000 kL capacity) and 2046 (800,000 kL capacity). This will increase the total availability of J100 from 1,764,173 kL (in 2040) to 2,853,710 kL (in 2060). The total CO2 emission reduction achieved by 2060 will reach more than 8 million tons, exceeding the CO2e reduction target of 7.7 million tons CO2e. The bioavtur mix in 2060 is predicted to reach 25%, or J25. The incorporation of SAF into the aviation industry's fuel mix marks a significant transition from fossil fuels to more sustainable renewable energy. Meanwhile, global SAF supply through 2022 reached only 240,000 tons (equivalent to 300,000 kL). Although this represents a 500% increase from 2019, this figure still represents less than 1% of global conventional aviation fuel production. This indicates that global SAF supply remains very limited. One factor hampering SAF supply is the demand for SAF itself. The average global SAF price reached USD 2,437/ton (equivalent to IDR 29,244 per liter), or approximately 2.2 times the average global conventional aviation fuel price.

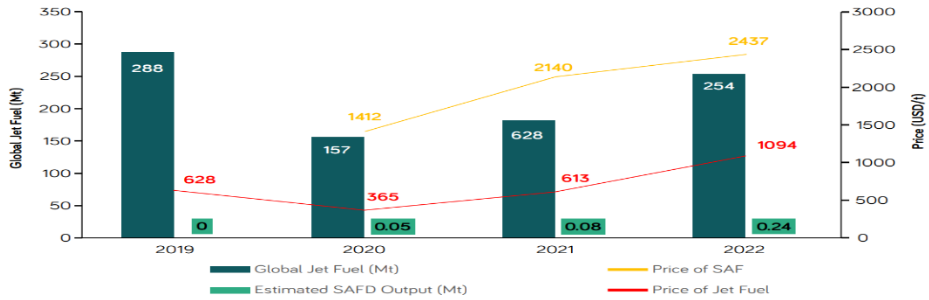

Figure 8. Global SAF Supply and Prices

Source: S&P Global Commodity Insight (Platts), IATA Sustainability & Economics 2022

However, as pressure to achieve net-zero emissions in the aviation industry increases, SAF production capacity continues to increase. The International Air Transport Association (IATA) announced that overall biofuel production is projected to reach an estimated capacity of at least 69 million kL (55 million tons) by 2028. SAF will be part of this increase, achieved through the construction of new biofuel refineries and the expansion of existing facilities. Production is geographically distributed across North America, Europe, and the Asia-Pacific. If renewable energy production reaches 69 million kL by 2028 as expected, the projection to reach 100 million kL (80 million tons) by 2030 will be on track. Assuming 22.5% of this amount is produced as SAF, the biofuel industry could reach 22.5 million kL (18 million tons) of SAF production by 2030, as shown in Figure 9 below.

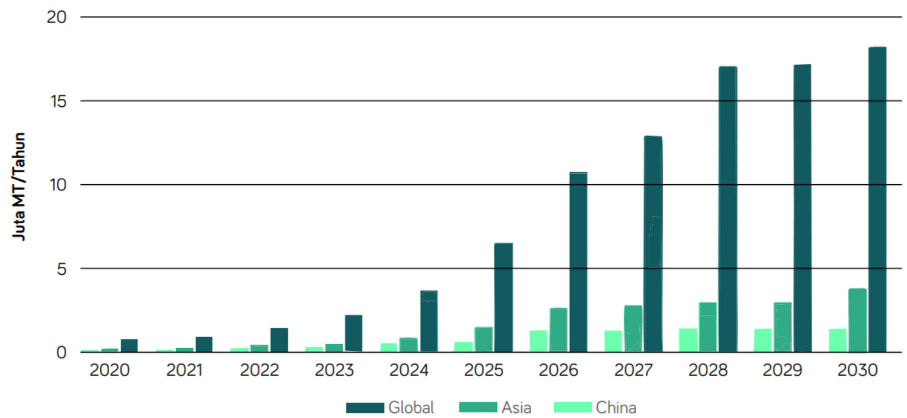

Figure 9. Global SAF Production Projection

3.3 Sustainable Raw Material of Bioavtur

The selection of raw materials using the MCDA method selects raw materials by first identifying several types of raw materials that can be used and have the potential to be used. This is because some raw materials are available in much larger quantities than others in the same group. This has indirectly reduced the opportunities for other materials. The materials reviewed are palm oil, coconut oil, used cooking oil, palm acid oil (PAO), palm oil harvesting residue biomass (Biomass of Palm), rice harvesting residue biomass (Biomass of Paddy), roundwood production residue biomass (Sawdust), particle-type processed wood production residue biomass (Woodchips), molasses, and the organic fraction of municipal solid waste (OFMSW). The processing technologies used to process the raw materials reviewed are derived from existing and future technologies, such as Hydroprocessed Esters and Fatty Acids (HEFA), Fischer-Tropsch (FT), Alcohol to Jet (ATJ), Catalytic Hydrothermolysis (CH), Hydroprocessed Depolymerized Cellulosic Jet (HDCJ), Direct Sugar Conversion to Hydrocarbons (DSHC), and Aqueous Phase Reforming (APR). Furthermore, assessment criteria for each of these raw materials need to be determined. To ensure a fast, yet focused selection process, the following criteria were selected. The first criteria is Raw Material Availability Criteria. This criterion is based on previously collected raw material quantity data. Within this criterion, score limits (1 and 10) are set, along with the production volumes of coconut oil (minimum) and palm oil (maximum). The second criteria is Global Technology Implementation

Criteria. Global technology availability represents the development of bioavtur production technology at the global level. The development of this technology is expressed by the technology's readiness score for large-scale production (beyond laboratory experimentation). This technology readiness assessment is analyzed using data on technology availability at the scale-up level (including pilot plants and demonstrations), as well as the development of the technology's literature. The third criteria is Technology Availability Criteria in Indonesia. This criterion is necessary to assess the implementation of technologies developed globally and available in Indonesia. The scoring system for this criterion is based on the results of the Global Technology Availability Criteria assessment, with assumptions about the adoption time for implementation in Indonesia.

The fourth criteria is Carbon Dioxide Emission Criteria. For bioavtur production, the sustainability parameter, represented by the amount of CO2-equivalent emissions, is a key factor in feedstock selection. The fifth criteria is Sustainability Criteria. Sustainability is quantified using the life cycle emissions factor (LCEF) for a CORSIA-eligible fuel, expressed in gCO_2 e/MJ for each feedstock category. The last criteria is Technology Flexibility Criteria. The criteria for suitability of raw materials to the technologies previously reviewed are based, in brief, on the number of technologies available for a given type of raw material. Assessments using the above criteria are conducted over several periods until the net zero carbon (NZC) target is met by 2060. 2060 is used as the end of the assessment period. The current year, 2025, is chosen as the starting year, but 2020 is considered representative of the period. This is used to simplify the division of the assessment period from 2020 to 2060 into 10-year intervals. The final MCDA Score Calculation Results can be shown in Table 1.

Table 1. Final MCDA Score Calculation Results

No	Types of raw materials	Availability of Raw Materials	Global Technology Implementation	Technology Availability	CO2 emissions	Alter natives	Total
1	Crude Palm Oil (PSE, 2024)	2.60	4.60	1.50	0.09	0.13	8.92
2	Coconut Oil (JST, 2024)	0.29	4.60	1.50	0.09	0.13	6.61
3	Used Cooking Oil (Muthmainah, 2025)	0.60	4.60	1.50	0.68	0.13	7.51
4	Palm Acid Oil (Hambali, 2010)	0.26	4.60	1.50	0.51	0.13	7.00
5	Biomass of Paddy (Adha et.al, 2026)	2.29	0.46	0.15	0.84	0.22	3.96
6	Biomass of Palm Oil (Nabila et al, 2023)	2.27	0.46	0.15	0.82	0.22	3.92
7	Sawdust (Puschnigg et al, 2023)	1.03	1.29	0.15	0.90	0.22	3.59
8	Woodchips (Velocys, 2026)	0.52	1.29	0.15	0.90	0.22	3.07
9	Molasses (Svejda, 1999)	0.31	0.46	0.75	0.50	0.22	2.23
10	Organic Phase Municipal Solid Waste (Jiang, 2022)	1.11	0.46	0.75	0.35	0.22	2.89

The MCDA analysis indicates that palm oil has the highest total score of 8.92, meaning palm oil is currently the top priority for bioavtur raw materials. The next priority is used cooking oil with a total score of 7.51. The third priority is PAO with a score of 7.00. The fourth is biomass paddy with score of 3,96. The sixth is biomass of palm oil with score of 3,92. The seventh is sawdust with score of 3,59. The eighth is woodchip with score of 3,07. The nineth is Organic Phase Municipal Solid Waste with score of 2,89. The final priority is molasses with the lowest total score of 2.23.

3.4 The Important Role Of Institutions In Sustainable Bioavtur Development

The institutional concept for bioavtur development should be based on the pentahelix. This model emphasizes collaboration between five stakeholders: government, academia, the community, business entities, and the mass media. These five stakeholders play a crucial role in meeting technical needs, as explained in Figure 10 below.

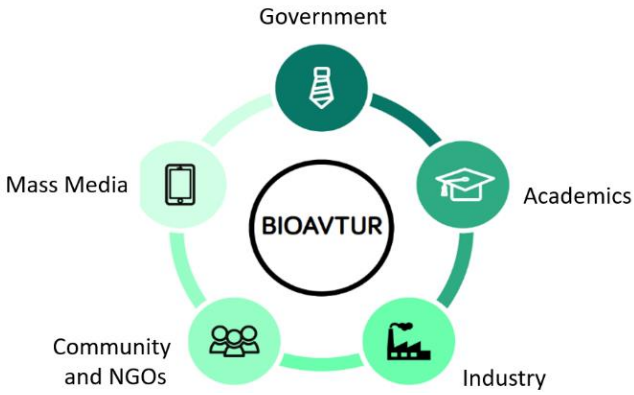

Figure 10. Pentahelix in Bioavtur Development in Indonesia

The pentahelix concept has received significant attention across various sectors, particularly in the context of sustainable development and collaboration. The pentahelix model emphasizes synergy and collaboration among five key stakeholders: government, academia, the public, the business world, and the media. In the context of sustainable aviation fuel (SAF) development, the pentahelix concept plays a crucial role in the development of a sustainable aviation fuel supply chain, as it involves multiple stakeholders, including government, academia, industry, and the media. The pentahelix model provides a framework for stakeholders to collaborate effectively, thus contributing to the development of commercial-scale SAF for the aviation industry.

In addition, the support of all parties is needed in the development of SAF for the energy transition to run optimally. The government formulates policies, regulations, national standards, guidance and supervision, and facilitators in the development of SAF. Academics create innovations that can be directly utilized by the community, improve the quality of human resources and encourage technology transfer. Industrial actors conduct business activities providing and utilizing fuel, supporting services, creating jobs, contributing to state revenue and economic activities. The community and NGOs act as a balance and partner of the government, providing advocacy and assistance for the community, conducting positive campaigns and actively participating in the development of SAF. Mass media educate the public on the importance of SAF and disseminate government programs to the community in an inclusive manner.

3.5 Development of Institutional Enablers for Sustainable Bioavtur

In mapping the roles of stakeholders in bioavtur development in Indonesia, the tasks and roles are based on the concept of Developing institutional enablers for sustainable bioavtur. The task descriptions for each component of the Pentahelix are derived based on the requirements of the roadmap. These descriptions, along with the relevant institutions, are presented in Table 2 below.

Table 2. Institutional Roles in the Implementation of the Bioavtur Roadmap

Aspect	Activity	Stakeholders
Technology Process Development	Development of HEFA	Academics: Conducting technology development Bioavtur Manufacturers: Providing Development and Testing Facilities Ministry of State-Owned Enterprises: Encourage relevant state-owned enterprises to develop technology
	Development of FT	Academics: Conducting technology development Bioavtur Manufacturers: Providing Development and Testing Facilities Ministry of State-Owned Enterprises: Encourage relevant state-owned enterprises to develop technology
	Development of Catalist	Academics: Conducting technology development Bioavtur Manufacturers: Providing Development and Testing Facilities Ministry of State-Owned Enterprises: Encourage relevant state-owned enterprises to develop technology

Aspect	Activity	Stakeholders
	Development of Blending	Academics: Conducting technology development Bioavtur Manufacturers: Providing Development and Testing Facilities Ministry of State-Owned Enterprises: Encourage relevant state-owned enterprises to develop technology
Supporting Infrastructure	Green Refinery Development	Bioavtur Manufacturers: Develop Green Refineries Coordinating Ministry for Economic Affairs: Encouraging Investment Development in Green Refineries
	Catalyst Factory Development	Academics: Conducting technology development Bioavtur Manufacturers: Providing Development and Testing Facilities Ministry of State-Owned Enterprises: Encourage relevant state-owned enterprises to develop technology
	Factory Development	Bioavtur Manufacturers: Develop Green Refineries Coordinating Ministry for Economic Affairs: Encouraging Investment Development in Green Refineries
	Catalyst Testing	Academics: Conducting technology development Bioavtur Manufacturers: Providing Development and Testing Facilities Ministry of State-Owned Enterprises: Encourage relevant state-owned enterprises to develop technology
Testing and Certification	Laboratory Testing	Academics: conducting laboratory testing Lemigas: conducting laboratory testing
	Static testing	Academics: conducting static testing Airlines: conducting static testing
	Ground test dan test flight	Academics: conducting static testing Airlines: conducting static testing Ministry of Transportation: Regulation and coordination Regarding the use of bioavtur for aviation
	Socialization and news	Ministry of Energy and Mineral Resources: Create regulations and a certification system for UCO raw materials Ministry of Agriculture: Support coordination for the provision of UCO raw materials Associations: Coordinate and provide UCO raw materials
	Technical standards for bioavtur	Ministry of Energy and Mineral Resources: Update the Directorate General of Oil and Gas Decree according to the latest standards
	Biomass waste raw material certification	Ministry of Energy and Mineral Resources: Update the Directorate General of Oil and Gas Decree in accordance with the latest standards Ministry of Agriculture: Support coordination for the provision of biomass waste raw materials Associations: Coordinate and provide biomass waste raw materials
Mandates and regulations	DMO policy for palm oil coconut oil	Coordinating Ministry for Economic Affairs: Promote the DMO policy for palm oil Ministry of Energy and Mineral Resources: Support the DMO policy for palm oil Ministry of Trade: Coordinate and support the DMO policy for palm oil
	DMO policy for UCO	Coordinating Ministry for Economic Affairs: Promote the DMO policy for UCO Ministry of Energy and Mineral Resources: Support the DMO policy for UCO Ministry of Trade: Coordinate and support the DMO policy for UCO
	DMO policy for biomass waste	Coordinating Ministry for Economic Affairs: Promote the DMO policy for biomass waste Ministry of Energy and Mineral Resources: Support the DMO policy for biomass waste Ministry of Trade: Coordinate and support the DMO policy for biomass waste
Market carrying capacity	Blending mandate	Ministry of Energy and Mineral Resources: Increase the blending mandate National Energy Council: Coordinate the NZE 2060 process Ministry of Finance: Create incentive regulations for bioavtur Directorate General of Economic and Fiscal Strategy: Promote incentive regulations for bioavtur

Table 2 shows a set of policy recommendations needed for bioavtur development and stakeholders contributions, starting from technology process development (HEFA, FT, ATJ), supporting infrastructure development (catalyst, biorefinery), testing and certification (laboratory, ground test, flight test, technical and certification standards), mandates and regulations (DMO, incentives), and market carrying capacity (mandate of blending).

3.6 Policy Implication and Recommendation

This study implies that a series of policies need to be promoted to support bioavtur production, including raw material security, technology options, ease of investment, incentive support to achieve economic viability, and balanced information dissemination. Institutional support is also needed to continue encouraging bioavtur development, emphasizing collaboration among five stakeholders: government, academia, the community, business entities, and the mass media. Therefore, this study recommends a series of policies to promote bioavtur production, ensure raw material security, support decarbonization technology options, ease of investment, provide incentives to achieve economic viability, and ensure balanced information dissemination. More technically, in order to make the sustainability of bioavtur development, all ministries, agencies, and local government must have a synergy, starting from technology process development (HEFA, FT, ATJ), supporting infrastructure development (catalyst, biorefinery), testing and certification (laboratory, ground test, flight test, technical and certification standards), mandates and regulations (DMO, incentives), and market carrying capacity (mandate of blending). Each ministry or institution plays an important role in bioavtur development, from the Coordinating Ministry for Economic Affairs, Energy and Mineral Resources, to Transportation, academics, airlines, and research and testing institutions.

Conclusion

The paper already identified the final MCDA, which concluded that palm oil has the highest total score of 8.92, meaning palm oil is currently the top priority for bioavtur raw materials. The next priority is used cooking oil with a total score of 7.51. The third priority is PAO with a score of 7.00. Some parameter of sustainable bioavtur demand in the future is explained by the relationship between the number of air passengers and the demand for aviation fuel, projected Global Aviation Fuel Demand to 2050, and Carbon Emission Projections. The sustainable supply of bioavtur in the future is supported by developing refineries that produce a certain amount of bioavtur from 2026 to 2050. The important role of institutions and the development of institutional enablers for sustainable bioavtur is described by mapping the roles of stakeholders in bioavtur development in Indonesia.

The aviation sector plays a crucial role in driving economic growth and reducing emissions in Indonesia. One of the biggest challenges in the aviation sector is implementing sustainability principles operationally. Sustainable Bioavtur is expected to have a significant positive impact on the aviation industry in Indonesia. Avtur consumption is projected to increase significantly from 4.9 million kiloliters in 2024 to 12.5 million kiloliters in 2060. This growth reflects the expansion of the aviation industry, which must be accompanied by an aggressive reduction in GHG emissions. The global target is an 85% reduction in emissions from 2019 and mandates sector-wide carbon-neutral growth in the international aviation industry starting in 2027. The Indonesian aviation sector must reduce emissions from 1.9 million tons of CO2e in 2024 to 25.6 million tons of CO2e in 2060. This reduction target can be achieved using more environmentally friendly Bioavtur. Currently, the bioavtur used is J2.4 produced by Pertamina RU IV Cilacap, and this will continue to increase as raw material availability increases and the bioavtur mandate is implemented.

The weakness of this study is that it only projects supply, demand, raw materials, and institutional roles based on existing conditions and limited previous statistical data. However, future conditions in Indonesia depend heavily on the direction of legitimate government policies and on highly dynamic and volatile global or international conditions. Suggestions for improvement from this study include placing greater emphasis on dynamic conditions, capable of adapting to social and economic changes, both globally and domestically in Indonesia.

Declaration of Generative AI Use

In preparing this paper, the authors used Google Translate to check grammar and clarity in the entire manuscript. No AI tool was used to generate analysis, findings, or conclusions. The tool was applied solely at the language-editing stage, after the substance of the manuscript had been fully written by the authors. No AI tool was used to design the research, collect data, perform the multi-criteria decision analysis, or interpret the results. The authors carried out all calculations, projections, and policy interpretations. Every sentence produced with language assistance was subsequently reviewed, verified, and revised by the authors to ensure accuracy of meaning and consistency with the original intent. The authors therefore take full responsibility for the entire content of this manuscript, including its accuracy, originality, and integrity.

Author Contributions

The first author wrote the initial draft of the manuscript. The second author supervised writing the entire manuscript. The third, fourth, and fifth authors checked, reviewed, and approved the final version of the manuscript. The first author was also responsible for the conceptualization of the study, data collection, data processing, and the multi-criteria decision analysis, as well as for preparing the tables, figures, and policy recommendations. The second author provided overall supervision, guided the research framework and methodology, and gave critical input on the structure and argumentation of the manuscript. The third author contributed to the validation of the technical data on bioavtur feedstock and conversion pathways, and reviewed the interpretation of the results. The fourth author contributed to the energy policy perspective, the demand and supply projection assumptions, and the analysis of the institutional roles. The fifth author contributed to the sustainability and biomass availability perspectives, and helped refine the discussion and conclusions. All authors participated in revising the manuscript critically for important intellectual content, have read and approved the final version submitted for publication, and agree to be accountable for all aspects of the work.

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Conflict of Interest

The authors declare that we have no conflicts of interest related to this study. We have no personal or financial relationships that could influence our work. None of the authors has any affiliation, employment, consultancy, or ownership interest in any organisation that may gain or lose financially from the publication of this paper. All views expressed here are those of the authors and do not necessarily represent the official position of their respective institutions.

References

Airport Council International. (2023). ACI World Airport Traffic Forecasts 2023–2052. Air Traffic Forecasts At Global, Regional, And Country Levels. Canada

Adha, A, Adhynugraha, MI. Purnamastuti, FN., Megawanto, Budiyanto, FC. (2026). Indonesia's path to sustainable aviation fuel: Evaluating feedstock potential from agricultural residue, Biomass and Bioenergy, Volume 209, 2026. https://doi.org/10.1016/j.biombioe.2026.108927.

Barron, F.H. and Barrett, 1996, "Decision Quality Using Ranked Attribute Weight", Management Science, 42, 11.

Coordinating Minister for Maritime Affairs and Investment. (2024). Roadmap for the Development of the Republic of Indonesia's Sustainable Aviation Fuel (SAF) Industry. Jakarta

European Union Aviation Safety Agency (2022) European Aviation Environmental Report 2022. Cologne. doi: 10.2822/129746

Hambali, E., M. Rivai, A. Thahar, A. Imam, dan D. Bariguna. 2010. Studi on The Potential of Waste Materials from CPO Mills in East Kalimantan The Republic of Indonesia. Research Collaboration Report between Mitsubishi Corporation Tokyo, Japan and SBRC LPPM IPB

IATA. (2022). S&P Global Commodity Insight (Platts), IATA Sustainability & Economics (2022)

ICAO. (2022). ICAO document - CORSIA Sustainability Criteria for CORSIA Eligible Fuels. https://www.icao.int/environmental-protection/CORSIA/Documents/CORSIA_Eligible_Fuels/ICAO

document 05 - Sustainability Criteria - November 2022.pdf
Inayah, I., Dzikra, K. G., al Irsyad , M. I., Kastaman, R., Irawan, I., & Halog, A. (2026). A preliminary assessment of sustainable aviation fuel potentials from municipal, agricultural, and plantation wastes in Indonesia. International Journal of Sustainable Energy Planning and Management, 48, 5–19. https://doi.org/10.54337/ijsepm.10615
Jiang, H. Wang, S. Baochen, L. (2022) Anaerobic digestion of organic fraction of municipal solid waste using a novel two-stage solid-liquid system, Journal of Cleaner Production, Volume 370, 2022, 133521, https://doi.org/10.1016/j.jclepro.2022.133521.
JST, (2024), "Inedible coconut oil utilized to create 100% biomass-based aviation fuel," Japan Science and Technology Agency. [Online]. Available: https://sj.jst.go.jp/news/202410/n1031-02k.html
Kigozi, R.O. and Aboyade, A.O. Operational Study and Simulation of a Biogas Upgrading Plant. Proceedings of the World Congress on Engineering 2014, 2014 Jul 2–4. London, UK.
Ministry of Energy and Mineral Resources. (2015). Ministrial Regulation of Energy and Mineral Resources Number 12 year 2015. Jakarta
Ministry of Energy and Mineral Resources. (2025). Ministrial Regulation of Energy and Mineral Resources Number 4 year 2025. Jakarta
Muthmainah, AK., Purwono, S., Aziz, MM. (2025). Pengembangan Proses dan Analisis Teknoekonomi pada Produksi Sustainable Aviation Fuel (SAF) dari Used Cooking Oil (UCO) di Indonesia. Universitas Gadjah Mada.
Nabila, R. Hidayat, W. Haryanto, A. Hasanudin, U. Iryani, DA. (2023). Oil palm biomass in Indonesia: Thermochemical upgrading and its utilization, Renewable and Sustainable Energy Reviews, Volume 176, 2023, https://doi.org/10.1016/j.rser.2023.113193.
Pertamina. (2025). Safeguarding Sustainability, Serving the Nation Wholeheartedly. Sustainability Report 2026. Jakarta
PSE, 2024, Studi Pemutakhiran dan Pemetaan Data Potensi Teknis Bioenergi sebagai Dasar Pengembangan Bioenergi Berbasis Lokasi, Yogyakarta
Puschnigg, S. Fraisl, KF. Lindorfer, J. (2023). Biorefinery development for the conversion of softwood residues into sustainable aviation fuel: Implications from life cycle assessment and energetic-exergetic analyses. Journal of Cleaner Production, Volume 386, 2023, https://doi.org/10.1016/j.jclepro.2022.135815.
Svejda, S. A., & Brookhart, M. (1999). Ethylene Oligomerization and Propylene Dimerization Using Cationic (α Diimine)nickel(II) Catalysts. Organometallics, 18(1), 65–74. https://doi.org/10.1021/om980736t
Thunder Said Energy. (2023). Global Jet Fuel Demand By Region And Forecasts. https://thundersaidenergy.com/downloads/global-jet-fuel-demand-by-region-and-forecasts/
Velocys. (2026). From forest floor to first flight: Proving SAF from woody biomass. Toyo Engineering Corporation, Japan.