Sustainability indicator evaluation for biomass feedstock in the biojet supply chain using Fuzzy Delphi method

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Abstract. In recent years, the production and consumption of traditional fossil jets have contributed significantly to CO_2 emissions. ICAO's agreement establishes a 2050 net-zero-emission (NZE) goal and outlines a process for states to achieve the accord. Indonesia, like many other countries, is part of international agreements and initiatives aimed at reducing carbon emissions. Producing bio-jet fuel as renewable aviation fuel aligns with these commitments, contributing to global efforts to achieve carbon neutrality. The Indonesian government issued a government instruction through ESDM regarding the target for blending bio-based fuel for aviation fuel 5 by 2025. The purpose of this research is to analyze metrics that need to be evaluated across the biojet fuel supply chain, contributing to a more holistic understanding of sustainability in the context of sustainable aviation fuels (SAF). Potential biomass from Indonesia was evaluated considering technical factors, economic factors, environmental and social factors, and blend limit already approved by ASTM International for the use of bio jet fuels into fossil jet fuel. This research design uses a mixed method, where raw material exploration is carried out using a qualitative approach. The results indicate that 11 validated indicators must be evaluated in designing a sustainable biomass feedstock framework for biojet fuel production in Indonesia. The technical dimension, particularly technology scalability and production volume, is crucial, with significant progress made in bio-jet production platforms like FT and HEFA, which are approved for up to 50% blending with fossil kerosene, while other technologies like microbial sugar-to-jet and ATJ have lower blend approvals.

1. Introduction

Aviation is one of the most important global economic activities in the modern world. The biggest impact of aviation on the environment is greenhouse gas emissions from residual fuel combustion. The amount of anthropogenic carbon dioxide (CO_2) emissions produced by the aviation sector into the atmosphere doubled from the mid-1980s to 2018 [1]. In 2022 aviation

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accounted for 2% of global energy-related CO_2 emission. The aviation sector creates 13.9% of the emissions from transport, making it the second biggest source of transport GHG emissions after road transport [2-3]. Ref. . [1] reported that in 2018 CO_2 emissions from the aviation sector were 1.04 billion tonnes of CO_2. Therefore, various important efforts have been made to reduce CO_2 emissions produced by the aviation sector.

Decarbonization of the aviation industry by 2050 has been set as a global goal. A long-term global aspirational target (LTAG) of net zero carbon emissions from international aviation by 2050 was accepted by the 184 member nations of the International Civil Aviation Organization (ICAO) in 2022. The worldwide aviation industry has started implementing de-carbonization strategies, particularly by promoting Sustainable Aviation Fuel (SAF). SAF can be made from a broad range of sustainable feedstock, including carbon that has been directly absorbed from the atmosphere, residual forestry wastes, and used cooking oils.

It is estimated that the aviation industry will still depend on liquid fuel until 2050, and it will not be possible to use hydrogen or electricity. Airbus reported that there are approximately 15,750 aircraft in the world, and it is projected to reach 32,000 by 2028 [2-3]. According to Yilmaz and Atmanli [4], 3 L of aviation kerosene per 100 km traveled are consumed. Efforts to reduce petroleum consumption in aviation through de-carbonization are expected to have a positive impact on climate change.

Biomass is the main feedstock for the biofuel production used in ground transport [9] due to its renewable condition [5-7]. Similar to this, the fuels derived from biomass have the greatest potential for usage in aviation, which has emerged as the most popular mode of transportation. Any biomass that contains carbs, whether it comes from plants or animals, is regarded as an energy source.

Indonesia, with its abundant natural wealth, has the potential to become the world's bioenergy or biofuel reservoir. Bioenergy is one of the new renewable energy (NRE) which supports the energy transition towards net zero emissions [8]. The potential that really cannot be ignored is the availability of large areas of land to cultivate plants that have potential as sources of bioenergy raw materials. Here what is meant by bioenergy includes the use of biomass, biodiesel, bioethanol, biogas, or bioavtur or bio jet as alternative energy sources.

In aviation, the idea of a "net-zero emission target" denotes a commitment to balance the emissions generated by the sector with an equivalent quantity of emissions eliminated or offset. A vital objective for the aviation industry is to reach net-zero emissions as part of larger initiatives to lessen the industry's environment.

Globally, the Air Transport Action Group organized an industry-wide Net Zero goal for the aviation industry, the first such commitment by an entire sector. Meanwhile, member states of the International Civil Aviation Organization (ICAO) agreed on a long-term aspirational goal (LTAG) of net zero carbon emissions for the aviation sector by 2050. There is now more demand than ever for SAF and sustainable flight. Beyond SAF, new technologies like battery-electric flight and hydrogen are expected to account for 21% to 38% of the carbon reductions in a net zero 2050 scenario [9-11]. Increasing operating efficiency, using sustainable aviation fuels (both synthetic and bio-based), and utilizing battery electric and hydrogen propulsion technologies are some ways to reach net zero by 2050.

Indonesia has been a member of the IEA since 2015 and has committed to achieving zero emissions net by 2060 or sooner. To achieve NZE, Indonesia has changed its carbon emissions reduction target to 32% by 2030 from the initial target of 29%. Biofuel development is one of the strategic programs that is favored to support the achievement of this target.

The development of bioavtur in Indonesia has been initiated since 2015. Pertamina and ITB developed bioavtur with a concentration of 2.4 percent, which is currently called J2.4 bioavtur. This is a mixture of kerosene and palm oil 2.4 percent.

The development of bioavtur with co-processing technology is currently carried out through RBDPKO (Refined, Bleached, and Deodorized Palm Kernel Oil) processing carried out at Refinery Unit (RU) IV Cilacap owned by PT Pertamina (Persero). J2.4 is a mixture of bioavtur produced from 2.4% & RBDPKO raw materials. The mention "2.4" indicates the mixing percentage of bioavtur fuel in aviation fuel.

The raw material for bioavtur that has been developed in Indonesia uses Crude Palm Oil (CPO) which has been further processed and is still expensive. Meanwhile, CPO and the products produced by CPO are purchased by Europe, therefore in the long term, it is necessary to explore other raw materials that support the sustainability of the bioavtur development supply chain in Indonesia. Several countries have their innovations in using biomass for aircraft fuel which are adapted to existing transportation policies, so that the development of this fuel can be sustainable. With the fast growth of the Indonesian aeronautical industry, it is necessary to find alternative fuels that reduce greenhouse emissions without affecting engine performance. Considering that, all biofuels have an energy density less than petroleum-based fuels, it is key to use efficient technologies for an adequate conversion.

This research aims to analyze metrics that need to be evaluated across the bio jet fuel supply chain, contributing to a more holistic understanding of sustainability in the context of sustainable aviation fuels (SAF) and recommending the potential of various biomass feedstocks available in Indonesia for the production of sustainable bio jet fuel.

1.1. Feedstock for Sustainable Aviation Fuel (SAF)

An alternative fuel that lowers emissions from air travel is sustainable aviation fuel (SAF), which is produced from non-petroleum feedstock. SAF blends from 10% to 50%, depending on the feedstock and fuel production method, can be blended at varying percentages. The International Civil Aviation Organization (ICAO) reports that SAF has been utilized on more than 360,000 commercial flights at 46 different airports, most of which are located in the US and Europe.

Through 2035, net CO_2 aviation emissions are limited by the ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to 2020 levels. By 2050, the worldwide aviation sector hopes to achieve net zero carbon emissions. The best chance to achieve these objectives in the foreseeable future is with SAF. Aiming to reduce lifecycle greenhouse gas emissions by at least 50%, the Sustainable Aviation Fuel Grand Challenge, which was announced in 2021, unites several federal agencies to increase domestic consumption to 3 billion gallons in 2030 and 35 billion gallons in 2050.

The development of environmentally friendly aviation fuel derived from biomass is gaining momentum as one approach to achieving the global goal of reducing CO_2 emissions in the aviation sector [12]. In addition, the use of sustainable aviation fuel (SAF) is increasingly popular due to lower CO_2 emissions produced during combustion, reduced dependence on fossil fuels, and the availability of renewable resources. The common feedstock used for the production of biojet fuel is seen in Table 2. The different biomass and their region-wise availability are further major challenges in getting suitable quantities for production [13].

Sustainable aviation fuel (SAF) is made from sustainable feedstocks and shares many chemical characteristics with conventional fossil jet fuel. Throughout the fuel's lifetime, using SAF reduces carbon emissions when compared to the conventional jet fuel it replaces. Cooking oil and other non-palm waste oils from plants or animals, as well as solid waste from residences and companies, like paper, plastic, and textiles, and food scraps that would otherwise be disposed of in a landfill or burned, are some common feedstocks used [14].

Energy crops, such as algae and quickly growing plants, and forestry waste, such as scrap wood, are further possible sources.

Bio jet fuel sources can be broadly categorized into four pathways, namely hydrolysis of fatty acid esters (HEFA), Fischer-Tropsch (FT) gasification, alcohol, and energy into liquid [15-16]. Liquid hydrogen may serve as fuel in the long term, while electric aircraft powered by batteries are mainly seen as an option for short-haul flights. So far, the consumption of SAF is marginal, accounting for less than 0.1% of the global consumption of jet fuel [1], most of which is synthetic paraffinic kerosene from hydro-processed esters and fatty acids (HEFA-SPK) [12,17-20].

1.2. Previous Research

Table 1. Previous literature relevant to this study

No	Author	Title	Method	Result
1	[6]	Evaluation of the potential feedstock for bio jet fuel production: Focus in the Brazilian context	Descriptive analysis	Assessment of the possible feedstock for the generation of bio jet fuel: Particular attention to Brazil
2	[12]	Economic Opportunities And Challenges In Bio jet Production: A Literature Review And Analysis	Comprehensive literature review from 2003-2021	The demand-side elements (like growing demand for lower emissions) are linked to the highest-ranked possibilities, while supply-side issues (like high manufacturing costs) are linked to the highest-ranked obstacles. Like many other aspects, policy concerns are ranked highly and have the potential to impact supply and/or demand. However, they are also seen as opportunities as well as obstacles.
3	[21]	Oleaginous feedstocks for hydro-processed esters and fatty acids (HEFA) bio jet production in southeastern Brazil: A multi-criteria decision analysis	AHP and TOPSIS	The primary reasons soybeans scored top were their high agricultural maturity and less oil costs. Soybean should be utilized initially in the manufacturing of HEFA bio jets.
4	[22]	Short-Term and Long-Term Feedstock Bio Jet Fuel for Green Environment of Air Transport in Climate Change Awareness	Investigation using 4 pillars IATA's: technology, operations, infrastructure and economic instruments	Air transportation creates environmental concerns that need to be taken into account in strategic planning development for the bio jet fuel to be used in the near future in air transport operations for tenable greener skies, as environmental concerns in general transportation systems become more apparent.
5	[23]	Screening of non-edible (second-generation) feedstocks for the	MCDA tool, i.e., PROMETHEE GAIA	Of the 38 feedstocks, 20 were determined to meet international fuel standards. Using the MCDA tool, it can be shown that the

No	Author	Title	Method	Result
		production of sustainable aviation fuel		feedstock with the greatest ranking for producing sustainable aviation fuel is Ricinus communis, followed by Azadirachta indica, and the feedstock with the lowest ranking is Sterculia feotida L.
6	[24]	Barriers and drivers of biomass renewable energy as co-firing in industrial supply chain with bibliometric analysis	Bibliometric	This article examines Indonesia's current co-firing facilities, the nation's biomass supplies, and the obstacles that have been successfully recognized in the process.
7	[25]	Energy, exergy, exergoeconomic, and environmental assessment of different technologies in the production of bio-jet fuel by palm oil biorefineries	Exergoeconomic	Glycerol, biodiesel, and electricity all had unit exergoeconomic prices that were less than market rates; bio-jet fuel costs from hydrotreatment were almost identical to those from the Brazilian market, at 0.49 and 0.46 USD/L, respectively.
8	[26]	Feasibility Analysis of Compact-Mobile Biomass Pallet Technology as Renewable Fuel for Small and Medium Industries	Economic engineering	Biomass pallets as renewable energy are possible to use like B20 to meet small and medium industries (SMEs). Financially, the compact-mobile pallet industry feasible with NPV value of IDR 28.94 billion, IRR 21.82%, and 6-year PBP.
9	[27]	Towards social sustainability: Screening potential social and governance issues for bio jet fuel supply chains in Brazil	Literatur review and expert survey	Researcher found 13 social issues and 5 governance issues were selected for inclusion in the expert survey. Decision-makers can broaden their comprehension of the social aspect of sustainability by using the knowledge gained from this study.
10	[28]	Modelling and simulation of a multiple feedstock integrated biorefinery for the production of aviation biofuel and other biofuels	Computer-aided design and analysis	According to the results, bio jet fuel accounts for 33% of net gross profit, with an investment of 5.52 kW for every kW of energy produced by the products.
11	[29]	Solid waste biomass as a potential feedstock for producing sustainable aviation fuel: a systematic review	PRISMA analysis	The most popular conversion technique for producing bio-jet fuel is catalytic hydro-processing of waste lipid feedstocks, according to the findings.
12	[30]	Renewable aviation fuel by advanced hydroprocessing of biomass: Challenges and perspective	Evaluating the impact of reaction factors and the hydroprocessing technology of bio-jet fuel.	The bulk of research projects have adopted the hydrodeoxy-genation procedure to produce positive results in a single step process. Still, there are several limitations and difficulties with the one-step process that may be

No	Author	Title	Method	Result
				resolved, like researching possible feedstock or creating a catalyst.

2. Methods

2.1 Research Design

Research design is a planning framework for conducting research as a guide and reference in collecting and analyzing data. The research design used is a mixed qualitative and semi-quantitative approach. The purpose of this study was to evaluate the potential of Indonesian biomass to support a sustainable biojet supply chain using a qualitative approach. The measure of a sustainable biojet supply chain will be validated by experts and stakeholders. The priority feedstock that supports a sustainable biojet supply chain is evaluated by using the fuzzy Delphi method. This research requires data and information collected from concepts in the theory of literature as well as from previous studies which are then taken and entered into the research variables.

2.2 Data Analysis

Data analysis is done by combining a literature review, a previous study, and fuzzy Delphi technique. At the initial stage, elaboration of the measure of sustainability bio jet supply chain from literature review and previous study. The measure of sustainability bio jet supply chain of an Indonesian perspective was validated with the Delphi technique involving expert and stakeholders of the national biomass supply chain. The Delphi technique is very useful to finalize the measure of sustainability bio jet supply chain. The combined fuzzy Delphi-AHP technique as a decision support method provides practical means not only to select the measure of sustainable bio jet supply chain but also investigate the priority of feedstock and technology to achieve sustainable bio jet supply from Indonesia perspective.

3. Result and Discussion

3.1 Fuzzy Delphi Analysis

There are four steps that the researcher uses to explore the framework of sustainable biomass feedstock for biojet fuel production in Indonesia. Table 2 shows each step conducted to answer each question. Given this writing is only to get the framework of sustainable biomass feedstock for biojet fuel production from an Indonesia perspective, then steps 3 and 4 will not be discussed in this paper.

Table 2. Summary of activities in Fuzzy Delphi method

Activity	Description
Step 1	Elaboration of the main criteria's in the framework of sustainable biomass feedstocks for biojet fuel production based on document analysis, reports, and literature reviews.
Step 2	The validation of criteria in the framework of sustainable biomass feedstock for bio jet fuel production is based on expert agreement using the fuzzy Delphi method.
Step 3	The weighting of criteria in the framework of sustainable biomass feedstock for bio jet fuel production based on expert app pair comparison.
Step 4	The framework of sustainable biomass feedstock for bio-jet fuel production is validated from Indonesia's perspective.

Step 1 Elaboration of the criteria of the biomass feedstock sustainability framework for bio jet production

Biomass feedstocks vary widely in their characteristics and suitability for biojet fuel production. Factors such as the type of biomass, geographic location, agricultural practices, and processing methods can significantly influence the overall sustainability of the biojet fuel supply chain. Therefore, a systematic evaluation of biomass feedstocks is crucial to ensure that the chosen sources are not only technically and economically viable but also environmentally friendly and socially acceptable.

In Indonesia, the primary biomass feedstocks include palm oil residues, coconut residues, sugarcane bagasse, and various types of wood and agricultural residues. Each of these feedstocks has unique advantages and drawbacks. For instance, palm oil residues are abundant and have high oil content, making them a promising feedstock for biojet fuel. However, palm oil production has been associated with deforestation and other environmental concerns. On the other hand, agricultural residues like rice husks and sugarcane bagasse are often considered waste products, which can be sustainably utilized without additional land use.

The MCDM framework offers a systematic approach to evaluate and rank different biomass feedstocks based on a set of predefined criteria. These criteria can be broadly categorized into five main groups: technical, economic, environmental, social, and good governance.

1. *Technical Criteria*: These include factors such as the yield of biojet fuel per unit of biomass, the efficiency of the conversion process, and the quality of the resulting fuel. High yield and efficiency are crucial for the economic viability of the biojet fuel production process [6][21][23][24][25][29][30].
2. *Economic Criteria*: Economic factors encompass the cost of biomass feedstock, processing costs, and potential revenue from biojet fuel. Lower costs and higher revenue potential make a feedstock more attractive from a business perspective [6][12][22][23][25][26][28].
3. *Environmental Criteria*: Environmental impact assessment involves evaluating the carbon footprint, land use, water use, and potential biodiversity impacts of biomass feedstock production and processing. Minimizing negative environmental impacts is essential for the sustainability of the biojet fuel supply chain [6][22][23].
4. *Social Criteria*: Social acceptance and impacts include considerations such as job creation, effects on local communities, and potential food security issues. Ensuring positive social outcomes is important for the long-term viability and acceptance of biojet fuel projects [6][22][23][27].
5. *Good Governance Criteria*: Good governance plays a crucial role in ensuring the sustainability of the bio-jet fuel supply chain, particularly in the selection and management of biomass feedstocks. Effective Governance encompasses a range of

principles, including transparency, accountability, inclusiveness, and regulatory enforcement, which collectively contribute to the economic, environmental, and social sustainability of the biojet fuel industry [6][22][23][27].

Table 3. Elaboration the criteria of biomass feedstock sustainability framework for bio jet production

No	Criteria	Sub-criteria	Indicator	Description
1	Technological criteria [6, 21, 23-25, 29, 30].	Technology compatibility	Production Process	Suitability of raw materials with existing production technology
			Technology Scalability	The ability of technology to scale-up as production increases
		Availability and Supply	Production volume	Raw materials must be available in sufficient quantities to meet large-scale production needs
			Season ability	Seasonal availability of raw materials can affect production continuity*
		Final product quality	Chemical Composition	Compliance of the chemical composition of raw materials with bio-jet quality requirements
			Conversion Efficiency	The efficiency level of converting raw materials into biojet
		Energy content	Energy density	The level of energy that can be produced from a raw material per unit of weight or volume
2.	Economic criteria [6, 22-23].	Cost	Procurement cost	Costs of purchasing or collecting raw materials
			Transportation cost	Costs for transporting raw materials to production facilities
3.	Social criteria [6, 22-23, 27].	Technology scalability	Job creation	Potential to create jobs in raw material-producing areas
			Food safety	Does not interfere with local food production or cause land use conflicts
4.	Environmental criteria [6, 22-23, 27].	Environmental impact	Carbon Emissions	The level of carbon emissions from growing, processing, and transporting raw materials
			Land use	Impacts on land use, including deforestation and agricultural land conversion*
			Biodiversity	Impact on biodiversity in raw material growing areas

		Ingredient source	Renewable source	Preference for rapidly renewable raw materials such as energy crops*
			Waste and residue	Utilization of agricultural, forestry, or industrial waste to reduce waste*
5	Good Governance [6, 22-23, 27].	Regulations and Policies	Government Support	Incentives and policy support from the government for bio jet production
			Standards and Certification	Conformity to applicable sustainability and certification standards

* Excluded from the initial assessment process due to duplication considerations or not criteria but as feedstock

Step 2 Validation the criteria of sustainable biomass feedstock for bio jet production

In determining the criteria of sustainable biomass feedstock for bio jet production, researchers have conducted literature studies as discussed in the findings in step 1 shown earlier. Hence, the findings of this step 2 are aimed at assessing and validating based on a group of experts on criteria of sustainable biomass feedstock for bio jet production that have been selected. The expert group involved in verifying this element is very important as these experts are composed of those who are directly involved in the context of the study. The analysis of the study data for the fuzzy Delphi method is based on the conditions contained in the TFN (triangular fuzzy number) and defuzzification process. The condition for the TFN involves the threshold value (d) and the percentage of the expert agreement in which the threshold value (d) of each item (criteria and sub-criteria) measured must be less or equal to 0.2 (Cheng & Lin, 2002) experts must exceed or equal to 75.0% (Chu & Hwang, 2008; Murry & Hammons, 1995). The threshold value (d) will be analyzed using microsoft excel based on the following formula:

$$d(\tilde{m},\tilde{n}) = \sqrt{1/3[(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2]} \quad (1)$$

For the defuzzification process, there is only one condition, the value of the fuzzy score (a) must be greater than or equal to the value of α cut of 0.5. (Tang & Wu, 2010; Bodjanova, 2006) the score of this fuzzy score is equally analyzed using Microsoft Excel using the following formula:

$$A = 1/3 * (m_1 + m_2 + m_3) \quad (2)$$

For this second step, there are 10 experts who have been identified for viewing, discussing, evaluating, and validating the criteria required for sustainable biomass feedstock for bio jet production. All of these criteria are very important to discuss whether they are accepted or rejected and confirmed on the basis of agreement from a group of experienced experts in the context of sustainable feedstock.

In this sustainable biomass feedstock framework for bio jet production, the indicators given to the experts are stated in Table 4. The threshold value (d), expert consensus percentage, defuzzification, and indicator position for all the criteria are shown in Table 4.

The findings show threshold value (d) and percentage of expert group. 13 criteria include the sustainable biomass feedstock framework for biojet fuel. Table 5 shows the final findings of the key indicators of sustainable biomass feedstock for bio jet production that have been negotiated by experts' panel. Referring to the criteria and sub-criteria, the indicator (KPI) (I2) Technology Scalability is the most important indicator followed by (I3) Production Process; (I8) Job Creation; (I9) Food Safety; (I10) Carbon Emission; (I11) Biodiversity; (I6) Procurement Cost; (I1) Production Process; (I7) Transportation Cost; (I4) Conversion

Efficiency; (I5) Energy Density; (I12) Government Support; and the last indicator is (I13) Standard and Certification.

From the findings of the analysis using the fuzzy Delphi method carried out, the researchers identified the indicators as agreed by the expert. The criteria were prioritized by the experts in each dimension or criteria. The result showed that all the indicators need to be evaluated in designing the framework of sustainable biomass feedstock for bio jet fuel production in Indonesia perspective. On the technical dimension, the experts agreed that these should include: production process, technology scalability, production volume, conversion efficiency, and energy density. These indicators indicate that technical dimension which incorporates technology scalability and production volume should be focused on sustainable biomass feedstock for biojet production. There has been significant progress in research on bio jet production platforms and several have been approved for industrial scale. Fig. 1 shows the relative maturity of these technologies in terms of fuel readiness level (FRL) versus feedstock availability resources.

Table 4. Research finding for indicators of sustainable biomass feedstock for bio jet production

Indicator	Description	TFN Condition		Defuzzyfication Process Term				Expert Consensus
		Threshold Value (d)	Expert Consensus (%)	m1	m2	m3	Fuzzy Score (A)	
I1	Production Process	0.060	70%	0.450	0.700	0.950	0.700	Accepted
I2	Technology Scalability	0.156	90%	0.600	0.850	1.000	0.817	Accepted
I3	Production volume	0.165	100%	0.550	0.800	1.000	0.783	Accepted
I4	Conversion Efficiency	0.082	70%	0.650	0.900	1.000	0.850	Accepted
I5	Energy density	0.173	70%	0.650	0.900	1.000	0.850	Accepted
I6	Procurement cost	0.200	70%	0.600	0.850	1.000	0.817	Accepted
I7	Transportation cost	0.036	70%	0.600	0.900	1.000	0.833	Accepted
I8	Job creation	0.164	80%	0.450	0.700	0.900	0.683	Accepted
I9	Food safety	0.184	90%	0.400	0.650	0.850	0.633	Accepted
I10	Carbon Emissions	0.128	90%	0.550	0.800	0.950	0.767	Accepted
I11	Biodiversity	0.181	90%	0.550	0.800	0.950	0.767	Accepted
I12	Government Support	0.184	90%	0.600	0.850	1.000	0.817	Accepted
I13	Standards and Certification	0.128	100%	0.600	0.850	1.000	0.817	Accepted

Condition:
Triangular fuzzy numbers:
-Threshold value (d) ≤ 0.2
-Percentage of experts consensus > 75%

Defuzzyfication:
-Fuzzy score (a) ≥ α – cut value = 0.5

Having commercial readiness or fuel readiness level-FRL > 7, bio-jet fuel, FT, and HEFA pathway methods have been approved up to 50% blended with fossil kerosene (ASTM, 2019). Fuel approval is a certification from a recognized authority and is achieved after laboratory testing, technical evaluation, and successful pilot-scale plants. Microbial sugar-to-jet pathway and ATJ technology have also been approved but at lower blends.

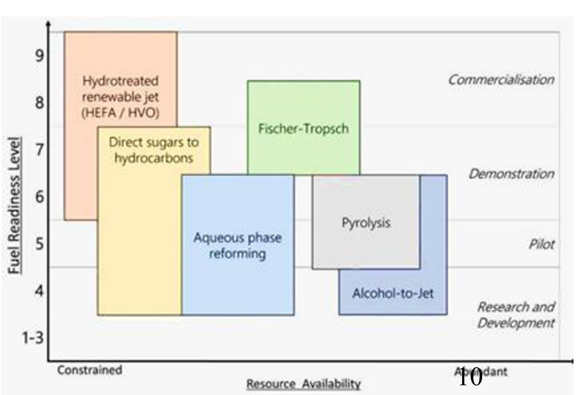

Fig. 1. Future scope for adapting the process to commercial level is subject to resource availability and technology maturity (Bosch et al., 2017, Processed).

An important factor in selecting feedstock or raw material for bio jet fuel production is their availability. For cultivation raw materials, availability and yield potential are interrelated. For generation-1, Indonesia has great potential to process palm oil, palm kernel oil, coconut oil, and Kemiri Sunan *oil* into bio jet. Palm oil is the most potential 1st generation feedstock for bio jet production in Indonesia due to its abundant availability and high oil content, making it efficient to convert into biojet fuel. Apart from palm oil, the potential and prospects of coconut are also very large as a raw material for biojets in Indonesia. The type of coconut used for bio jet production comes from coconuts that are not suitable for consumption. The supply of unsuitable coconuts can reach 20-30%. Kemiri Sunan (*Reutealis trisperma*) is a non-edible oil that can also be an alternative raw material for biojets through the HEFA pathway.

4. Conclusion

Evaluating biomass feedstocks for sustainable aviation fuel production in Indonesia using a multicriteria decision-making framework offers a comprehensive and balanced approach to address the complexities involved. By considering technical, economic, environmental, social, and good governance criteria, the mcdm framework ensures that suitable and sustainable feedstocks are selected. This approach not only supports the development of a robust biojet fuel supply chain in Indonesia but also contributes to global efforts to reduce the carbon footprint of the aviation industry and promote sustainable energy practices. Based on the results of the fuzzy Delphi analysis, the expert consensus accepted 11 indicators in evaluating the sustainability of biomass raw materials for biojet fuel production in Indonesia. These indicators can be reviewed from the dimensions of technological readiness, environmental impact, social acceptance, financial feasibility, and good governance. Good governance is fundamental to the sustainability of biomass feedstocks in the bio-jet fuel supply chain.

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