Decision Analysis for Biomass Utilization in Bioenergy Development in Palm Oil Mill

Fitra Lestari, Fani Afida Faroha, Petir Papilo
Industrial Engineering Department, Faculty of Science and Technology
State Islamic University Sultan Syarif Kasim Riau, Indonesia
fitra.lestari@uin-suska.ac.id, pilo_ukm@yahoo.com, 11850222283@students.uin-suska.ac.id

Marimin
Department of Agro-industrial Technology
IPB University (Bogor Agricultural University)
marimin@apps.ipb.ac.id

Abstract

Indonesia has many palm oil mills and plantations spread across various regions. As a result, the increasing number of palm oil mills is accompanied by an increase in waste. Biomass is waste from palm oil mills that impact environmental pollution and is used as a source of electrical energy. This study aims to make decisions on the potential utilization of biomass for electricity bioenergy at one of the palm oil mills in Riau. Interviews, observation, and distribution of pairwise comparison questionnaires were carried out for data collection. This study begins with identifying the criteria for potential biomass utilization from oil palm. Then, it is formulated into a decision-making hierarchy to determine potential biomass for bioenergy development based on utilization goals and use of technology processed by the Fuzzy AHP (*Analytical Hierarchy Process*) method. The finding shows the main purpose of utilizing biomass is to meet energy needs in the production process at palm oil mills. Then, the appropriate generation technology for electricity bioenergy is biogas, and the selected biomass potential is *Palm Oil Mill Effluent* (POME). The implications of this study provide recommendations to management and policymakers to utilize palm biomass as a source of bioenergy electricity.

Keywords
Bioenergy, Palm Oil, Fuzzy AHP (Analytical Hierarchy Process), Decision Making, Indonesia.

1. Introduction

Indonesia to meet its economic needs mainly come from the agricultural sector. One of the most potential commodity sectors in Indonesia is palm oil. Palm oil is Indonesia's most potential agricultural commodity. The increasing area of oil palm agricultural land, along with the increasing number of companies operating in this sector, leads to a high intensity of waste produced from the production process which can impact environmental pollution. The Indonesian government continues to strive to maximize the use of agricultural commodities, especially palm oil, to meet national energy needs (Papilo and Bantacut 2016). Thus, Indonesia needs to find out the status of the sustainability of agro-industry development by taking into account the potential utilization of waste as bioenergy development.

Bioenergy is energy from living things or other organic materials. A study asserts that bioenergy is a renewable energy with good prospects for development due to limited petroleum in Indonesia (Langer *et al.*, 2021). Bioenergy generally consists of three types: biofuels (bioethanol, biodiesel), biogas, and biomass (wood chips, bio-bonding, and agricultural waste) (Papilo *et al.* 2018). Factories are asked to continue looking for the latest innovations to reuse the waste they produce. This innovation can produce energy to replace fossil energy sources with palm oil-based renewable electricity. Several modern bioenergy technologies are currently being developed using biomass, such as biodiesel, bioethanol, fuel oil, and biogas (Ambaye *et al.* 2021; Chen *et al.* 2019). Biodiesel is used as an alternative fuel to new or used vegetable oil (Huang *et al.*, 2012). It is processed through transesterification, esterification, or a combination of the two processes . The technology currently being discussed is bioethanol. Bioethanol is ethanol produced through biological processes from starch and cellulose sources (Tse *et al.* 2021). Bioenergy is currently in the spotlight because of its good sustainability. Co-firing is a generation technology that adds biomass as a partial replacement fuel for coal boilers (Xu *et al.* 2020). In coal boilers, co-firing is often used to assist the combustion process by utilizing the fire it produces for palm oil boiler engines. With the limited petroleum and palm oil waste, along with the increasing area of oil palm land, it is necessary to utilize palm oil waste. Factories are useless waste. However, technological developments can utilize this waste material called oil palm biomass.

Oil palm biomass is widely used for various purposes (Santi *et al.* 2019; Zamri *et al.* 2022). Empty fruit bunches are used for compost and biochar, palm stems and fronds used for a mixture of compost, animal feed, shells, and fiber as boiler fuel in palm oil mills. The shells are also used to improve the quality of calories, moisture content, density, and ash content to manufacture charcoal bio briquettes. Fiber or fiber from oil palm fruit can be used as a planting medium. Besides, fiber can be used as a source of biogas, biopellets, and animal feed. Palm Oil Mill Liquid Waste (POME) is generally used as a power plant by co-firing. Biomass from oil palm plantations has a use value that can add to the value of this biomass and has the potential to become a source of renewable energy (Shuit *et al.* 2009). Figure 1 is the Mass Balance of Oil Palm Fresh Fruit Bunch (FFB) Processing.

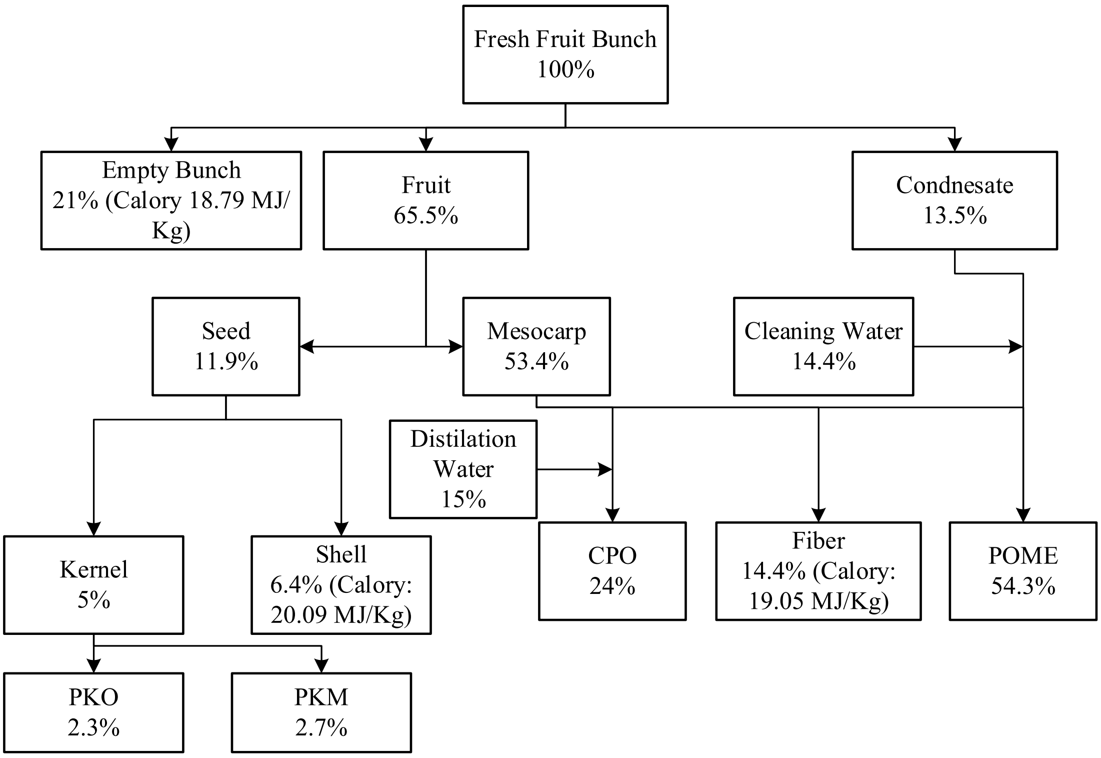

Figure 1. Mass balance of oil palm FFB processing (Source: (Hambali and Rivai, 2017))

This research was undertaken at one of the palm oil mills in Riau, Indonesia, which is a state-owned palm oil mill. This factory utilizes waste by using co-firing to burn Bioler instead of shellfish. Most of the waste generated from the Lubuk Dalam palm oil mill has been reallocated to fulfill 3R (reuse, reduce, and recycle). Empty fruit bunches are used as fertilizer, liquid waste (POME) is used for fertilizer and co-firing, fiber is used as co-firing fuel, and other wastes such as shells also have a selling value as fuel. Due to the low selling value of shellfish in Indonesia, the company chose to sell shellfish overseas. This study took data from one of the palm oil mills. The palm oil mill profile can be seen in table 1 which utilizes biomass as an energy source. Table 1 indicates that biomass utilization in this case study is not maximized. Thus, a study is needed to determine the potential of biomass waste for developing palm oil-based bioenergy. Of course, it is necessary to analyze the best decision to use palm oil waste, especially in an effort to meet the energy needs of the Palm Oil Mill.

Table 1. Utilization of biomass in the palm oil mills

Biomass type	Factory in general	Factory – case study
Fiber	Biogas, Boiler Fuel	Material of Boiler Fuel
Shell	Biogas, Boiler Fuel	Export
Empty Bunch	Biogas, Organic Fertilizer	Organic Fertilizer
POME	Biogas, Biodiesel, Co-firing	Co-firing
Midrib	Biogas	-
Stem	Biogas	-

2. Fuzzy AHP

The AHP method with Fuzzy was developed by Saaty, a continuation of the Analytical Hierarchy Process (AHP) method. The Fuzzy AHP method is used to determine the weight of the criteria and the sub-criteria in the hierarchy referred to by the researchers themselves based on books, field research, or knowledge possessed (Odusoro and Oke 2021; Putra *et al.* 2018). There is an additional treatment of the comparison of fuzzy matrices for the operation of the fuzzy number matrix itself with fuzzy numbers as a step of changing the weights of the fuzzy comparison matrix. Fuzzy Analytical Hierarchy Process is better and more valid in determining the goals or goals of several alternatives that are equivocal than the traditional AHP method (Liu *et al.* 2020). However, several algorithm variations aim to manage a fuzzy pair matrix, which is then converted to priority weights. Fuzzification is the process of changing the input data in the form of respondents who assess the correctness of crisp input or certainty into fuzzy input that has been determined based on its function. Then, do processing and reasoning using fuzzy input to produce fuzzy output, which is converted into crisp input based on the membership function that has been determined. To determine the degree of membership of the Fuzzy AHP, it is arranged in fuzzy or triangular fuzzy numbers (TFN). The AHP Fuzzy method has a core in comparing pairwise values , which are described with a ratio scale that has to do with fuzzy scale values.

The most potential biomass can be decided using the Fuzzy AHP method. The AHP Fuzzy Method is a combined method of elaborating a hierarchy from the views of several parties interested in an existing goal or objective and is described using fuzzy numbers. Then proceed to form a fuzzy comparison matrix. There is an additional treatment of the comparison of the fuzzy matrix for the operation of the fuzzy number matrix itself with the fuzzy number as a step for changing the weights of the fuzzy comparison matrix . After doing the analysis, a ranking is obtained that can cover the deficiencies of each AHP element which has many subjective properties.

3. Methodology

Data collection was undertaken through expert opinion from different field groups. Table 2 is the profile of the respondents in this study.

Table 2. Profile of respondents

No	Name	Position	Expert and experience
1	Respondent A	Researcher, University	System engineering, soft system for sustainable agro-industry engineering and agro-industry supply chain
2	Respondent B	Researcher, Government	Bioenergy and Industrial Systems
3	Respondent C	Researcher, University	Palm oil industry in supply chain strategy
4	Respondent D	Assistant in palm oil mill	Biomass Management and Biomass Development
5	Respondent E	Assistant in palm oil mill	Biomass Management and Biomass Development

The research methodology contains the steps or stages that will be undertaken during the research to decide on the potential utilization of biomass for electricity bioenergy at one of the palm oil mills. Figure 2 is the research stage.

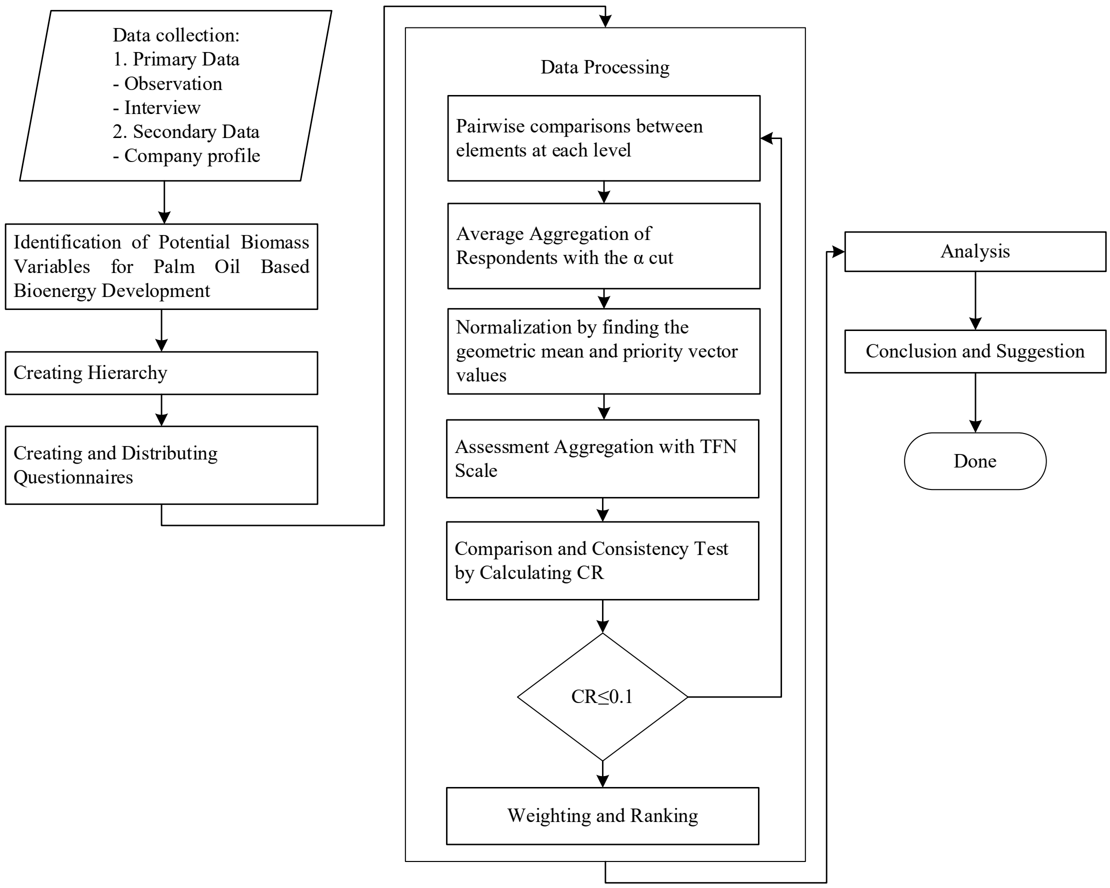

Figure 2. Research Stages

This research adopts the fuzzy analytical hierarchy process method in looking for potential biomass for bioenergy development. The AHP fuzzy method focuses on decision-making problems. The steps in data processing with the AHP fuzzy method (Odusoro and Oke 2021; Putra *et al.* 2018) are as follows:

1. Defining the problem, namely in determining what alternative biomass has the potential for bioenergy development, what technology can be applied, what aspects are used as a reference, what are the objectives, and what factors influence this potential.
2. Creating a hierarchy taken from alternatives, generation technology, objectives, and potential factors, which are interpreted into a structure with level 0 to level 4 and achievement of goals at level 0
3. The average aggregation of respondents is made using the α cut formula with an odd number 1-9. Then the pairwise comparison matrix is filled with the discounted value α.
4. Normalization is found by finding geometric averages and priority vectors.
5. Aggregation of respondents' ratings with a TFN (triangular fuzzy number) scale.
6. The comparison is used as a comparison matrix using the TFN scale. The consistency test serves to test how consistent the answers of the experts/respondents are. All elements are logically grouped and consistently ranked according to logical criteria because an assessment with high consistency will be necessary for decision-making.
7. The results of calculating the weight of each level and ranking

A hierarchy is a structure that contains elements following the level until a result or goal is obtained at level 0. This biomass hierarchy is carried out to make comparisons of objective elements, generation technologies, and alternatives. And there is a scale for determining the weight of each question. Respondents are expected to fill in questions based on field realization and according to the weight value on the scale. Figure 3 is a potential biomass hierarchy.

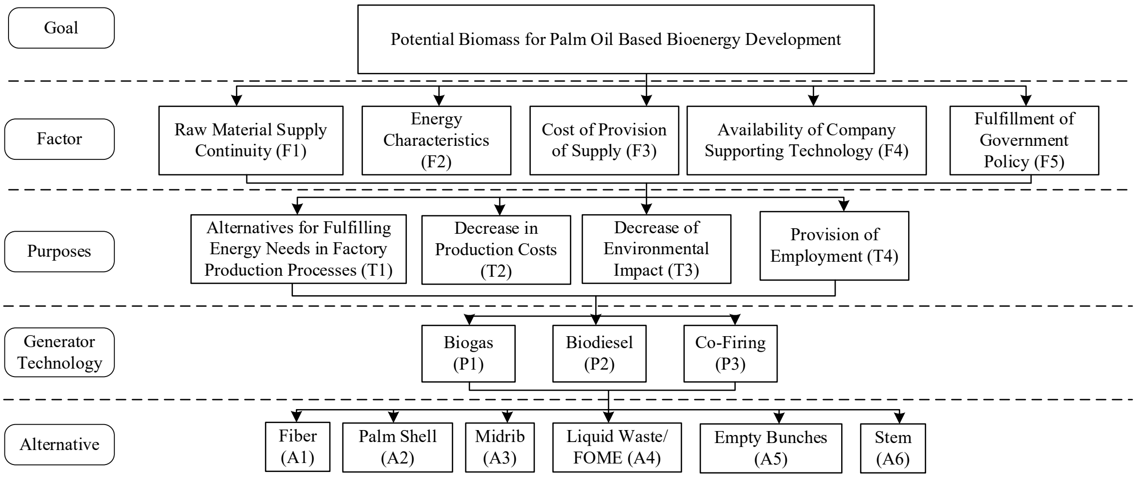

Figure 3. Potential Biomass Hierarchy

4. Finding

Several stages of processing that have been carried out adopt the Fuzzy AHP method, namely ranking the weight of each alternative. Table 3 is the result of weighting.

Table 3. The result of weighting ranking

Level	Parameter	Bobot	%	Ranking
Purpose	T1	0.288	28.78	1
	T2	0.282	28.17	2
	T3	0.198	19.75	4
	T4	0.233	23.29	3
Generator Technology	Biogas (P1)	0.535	53.49	1
	Biodiesel (P2)	0.248	24.82	2
	Co-Firing (P3)	0.217	21.69	3
Alternative	Fiber (A1)	0.138	13.79	4
	Palm Shell (A2)	0.186	18.59	2
	Midrib (A3)	0.092	9.21	5
	Liquid Waste (A4)	0.364	36.43	1
	Empty Bunch (A5)	0.140	13.95	3
	Stem (A6)	0.080	8.02	6

Table 3 shows the ranking at the highest objective level, found in Alternatives to fulfilling energy needs in the factory production process (T1). At the generation technology level, the highest ranking is obtained from biogas(P1); at the alternative level, the highest level is obtained by liquid waste (A4). Thus, this study found the most potential biomass in developing palm oil-based bioenergy. Figure 4 is a hierarchy and weighting value in this case study.

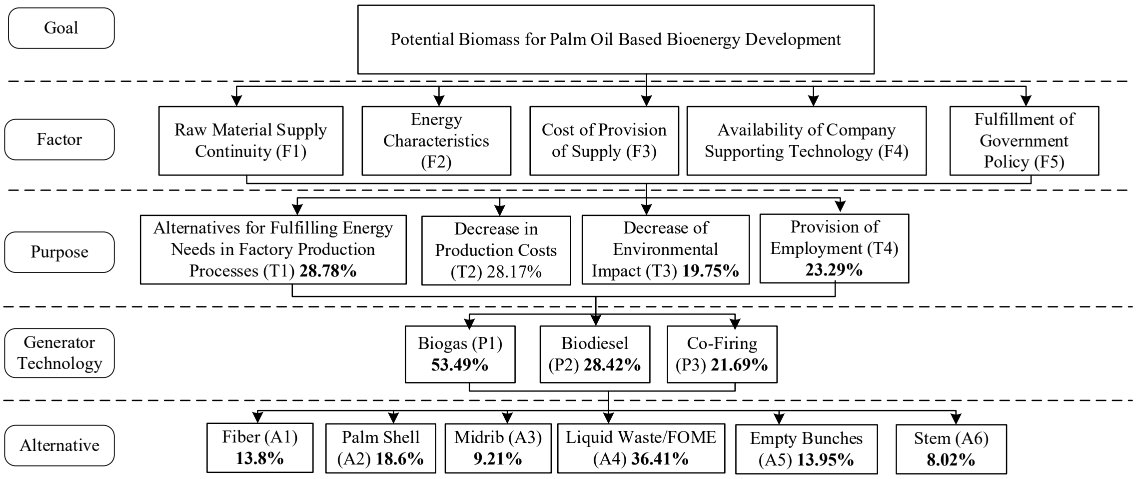

Figure 4. hierarchy and weighting values

5. Discussion

This study has shown each oil palm biomass's potential level in a palm oil mill. The data processing results using the Fuzzy AHP method found that

1. the T1 value (Alternative to meet energy needs in the factory production process) is 0.288 with the first rank. Then, T2 (reducing production costs) is 0.282 in the second rank, T4 (provision of employment) is 0.233 in the third rank, and T3 (reducing environmental impact) has a weight value of 0.198 in the fourth rank.
2. The power plant technology level shows that biogas (P1) has a weight value of 0.535 with the first rank, biodiesel (P2) has a weight value of 0.248 with the second rank, and co-firing (P3) has a weight value of 0.217 with the third rank.
3. In the alternative level, the value of liquid waste/POME (palm oil meal effluent) (A5) is 0.364 with the first rank, palm shells are 0.186 with the second rank, empty fruit bunches is 0.140 with the third rank, fiber is 0.138 with the fourth rank, fronds have a weight value of 0.092 with the fifth rank, and stems have a weight value of 0.080 with the sixth rank.

The implications of this study have provided recommendations to decision-makers below. Based on the expert's assessment, at an objective level, the results of T1 (Alternative for fulfilling energy needs in the factory production process) are considered as the main goal in finding the most potential biomass for sustainable palm oil-based bioenergy. Then for the selection of generator technology that can be used as a recommendation for companies, biogas (P1). Biogas is considered the most effective for use in palm oil mills because quite a lot of palm oil mill waste (POME) biomass is produced, which is around 0.6 tons, obtained from processing 1 ton of FFB. POME conversion to biogas is carried out by processing oxygen (aerobic). In terms of aerobic treatment, plants tend to be cheap compared to anaerobic. The data processing results show that the most consistent alternative recommendation used as biomass for the sustainability of palm oil bioenergy in this study is Liquid Waste/POME. Liquid waste is considered the most potential because its utilization can reduce environmental impact. Then, liquid waste is one of the most produced biomass in each production, which has the highest BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand) (organic content) content and is still used for biogas.

6. Conclusion

This study has succeeded in assisting decision-makers in the bioenergy sustainability of palm oil mills. Selection on the potential utilization of biomass for electricity bioenergy at one of the palm oil mills has been obtained. Then, this research recommends conducting a sustainability performance assessment on using palm oil mill effluent (POME). This study is needed to support the government's policy in implementing suitability in the palm oil industry.

References

Ambaye, T.G., Vaccari, M., Bonilla-Petriciolet, A., Prasad, S., van Hullebusch, E.D. and Rtimi, S., "Emerging technologies for biofuel production: A critical review on recent progress, challenges and perspectives", *Journal of Environmental Management*, Vol. 290 No. April, pp. 1–16. 2021.

Chen, W.H., Lee, K.T. and Ong, H.C., "Biofuel and bioenergy technology", *Energies*, Vol. 12 No. 2, pp. 1–12. 2019.

Hambali, E. and Rivai, M., "The Potential of Palm Oil Waste Biomass in Indonesia in 2020 and 2030", *IOP Conference Series: Earth and Environmental Science*, Vol. 65 No. 1, pp. 1–9. 2017.

Huang, D., Zhou, H. and Lin, L., "Biodiesel: An alternative to conventional fuel", *Energy Procedia*, Vol. 16 No. PART C, pp. 1874–1885. 2012.

Langer, J., Quist, J. and Blok, K., "Review of Renewable Energy Potentials in Indonesia and Their.pdf", *Energies*, Vol. 14 No. 7033, pp. 1–21. 2021.

Liu, Y., Eckert, C.M. and Earl, C., "A review of fuzzy AHP methods for decision-making with subjective judgements", *Expert Systems with Applications*, Elsevier Ltd, Vol. 161, pp. 1–30. 2020.

Odusoro, S.I. and Oke, S.A., "A Fuzzy Analytic Hierarchical Method to Reduce Imprecision and Uncertainty in Drilling Operation's Factor Selection Process for Unidirectional Carbon Fibre Reinforced Plastic Composite Plates", *International Journal of Industrial Engineering and Engineering Management*, Vol. 3 No. 1, pp. 17–26. 2021.

Papilo, P. and Bantacut, T., "Klaster Industri Berbasis Kelapa Sawit", *Jurnal Teknik Industri*, Vol. XI No. 2, pp. 87–96. 2016.

Papilo, P., Marimin, Hambali, E. and Sitanggang, I.S., "Sustainability index assessment of palm oil-based bioenergy in Indonesia", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 196, pp. 808–820. 2018.

Putra, M.S.D., Andryana, S., Fauziah and Gunaryati, A., "Fuzzy analytical hierarchy process method to determine the quality of gemstones", *Advances in Fuzzy Systems*, Vol. 2018, pp. 1–6. 2018.

Santi, L.P., Kalbuadi, D.N. and Goenadi, D.H., "Empty Fruit Bunches as Potential Source for Biosilica Fertilizer for Oil Palm", *Journal of Tropical Biodiversity and Biotechnology*, Vol. 4 No. 3, pp. 90–96. 2019.

Shuit, S.H., Tan, K.T., Lee, K.T. and Kamaruddin, A.H., "Oil palm biomass as a sustainable energy source: A Malaysian case study", *Energy*, Elsevier Ltd, Vol. 34 No. 9, pp. 1225–1235. 2009.

Tse, T.J., Wiens, D.J. and Reaney, M.J.T., "Production of bioethanol—a review of factors affecting ethanol yield", *Fermentation*, Vol. 7 No. 4, pp. 1–18. 2021.

Xu, Y., Yang, K., Zhou, J. and Zhao, G., "Coal-biomass co-firing power generation technology: Current status, challenges and policy implications", *Sustainability (Switzerland)*, Vol. 12 No. 9, pp. 1–18. 2020.

Zamri, M.F.M.A., Milano, J., Shamsuddin, A.H., Roslan, M.E.M., Salleh, S.F., Rahman, A.A., Bahru, R., *et al.*, "An overview of palm oil biomass for power generation sector decarbonization in Malaysia: Progress, challenges, and prospects", *Wiley Interdisciplinary Reviews: Energy and Environment*, Vol. 11 No. 4, pp. 1–24. 2022.

Biographies

Fitra Lestari is a Professor in Industrial Engineering Department at Sultan Syarif Kasim State Islamic University, Indonesia. He finished his Ph.D. project with a major area in Supply Chain Management at Universiti Teknologi Malaysia. He is currently a member of IEOM and has published several articles in international journals about Supply Chain Management, Logistics, and Performance Measurement.

Fani Afida Faroha is an industrial engineering student at Sultan Syarif Kasim State Islamic University, Indonesia. His area of interest is Multi-criteria decision making.

Petir Papilo received the Ph.D. degree from the Department of Agro-industrial Technology, IPB University, in 2019. He has been a Lecturer and an Academician with the Industrial Engineering Department, State Islamic University of Sultan Syarif Kasim, Riau. His current research interests include decision support system design for agro-industry, sustainability development for industry, palm oil supply chain, and institutional analysis for the industrial supply chain.

Marimin received the B.S. degree (Hons.) in agro-industrial technology from IPB University, Indonesia, in 1984, the M.Sc. degree in computer science from University of Western Ontario, Canada, in 1990, and the Ph.D. degree from Faculty of Engineering Science, Osaka University, Japan, in 1997. Since 2003, he has been a Professor of systems engineering at IPB University. His research interests include intelligent and fuzzy expert systems, multiple criteria decision making, and supply chain management. He is a member of the Indonesian Engineer Association and Indonesia Logistic and Supply Chain Management and Institute of Electronic and Electrical Engineer (IEEE)