Determination of Indonesian palm-oil-based bioenergy sustainability indicators using fuzzy inference system

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Abstract. Development of Indonesian palm-oil-based bioenergy faces an international challenge regarding to sustainability issue, indicated by the establishment of standards on sustainable bioenergy. Currently, Indonesia has sustainability standards limited to palm-oil cultivation, while other standards are lacking appropriateness for Indonesian palm-oil-based bioenergy sustainability regarding to real condition in Indonesia. Thus, Indonesia requires sustainability indicators for Indonesian palm-oil-based bioenergy to gain recognition and easiness in marketing it. Determination of sustainability indicators was accomplished through three stages, which were preliminary analysis, indicator assessment (using fuzzy inference system), and system validation. Global Bioenergy partnership (GBEP) was used as the standard for the assessment because of its general for use, internationally accepted, and it contained balanced proportion between environment, economic, and social aspects. Result showed that the number of sustainability indicators using FIS method are 21 indicators. The system developed has an accuracy of 85%.

1. Introduction

Bioenergy is a potential alternative energy source from biomass. Reducing the dependency on fossil fuel and being eco-friendlier are some of the advantages from the utilization of bioenergy. Palm oil is the most potential resource to produce bioenergy in Indonesia because of its availability; the area of palm plantation in Indonesia is estimated at 11.3 million hectares with palm oil productivity reaching 31.3 million ton/year\cite{1}. Various bioenergy products such as biodiesel, bio-oil, bioavtur, biopellet, biobriquettes and biogas can be produced from crude palm oil (CPO) and also the biomass namely shell, fiber, empty bunches and liquid waste. Thus, palm oil is a very potential raw material source for bioenergy.

One of bioenergy product which has a big potential to be exported is biodiesel. It is shown by biodiesel production capacity in 2014 was 3,961 million kl while the rate of domestic utilization was only 1,845 million kl\cite{2}. Consequently, there was still production excess which could be exported, contributing to the increase of national income.

The development of palm-oil-based bioenergy in Indonesia faces an international challenge regarding to sustainability issue, environmental, economic and social impact. Deforestation, reduction of
biodiversity and carbon stocks were considered as the impacts of palm oil plantation[3]. In addition, there are some other impacts that could occur in social and economic aspects such as decrement of land availability, rise of land price and conflicts between indigenous people or between indigenous people and the company[4].

There were some initiations in the making of standard which contain the criteria, indicators and the principle of the bioenergy sustainability. These initiations are the national, regional, international and multi-stakeholder initiations. Indonesia also has a sustainability standard for palm oil plantation named Indonesian Sustainable Palm Oil Certification System (ISPO). However, ISPO only contained indicators and principle of plantation sustainability or cultivation of palm oil. It has yet to include the indicators of palm-oil-based bioenergy production, whereas not all the existing indicators from other countries are appropriate to Indonesian palm-oil-based bioenergy sustainability indicator. Thus, Indonesia needs appropriate sustainability indicators for its palm-oil-based bioenergy.

The determination of the indicators has been carried out qualitatively using focus group discussion (FGD). This method has some advantages, for example varying data could be collected in shorter period time because the interaction between participants is more practical, flexible, and cost-efficient. Nevertheless, FGD has some disadvantages due to the complexity of the data collected so that it requires higher level- and longer duration of analysis[5]. Fuzzy inference system (FIS) is a method which maps an input to an output regarding to the determined factors. It has a mathematical framework which is capable of solving complex problems[6]. Therefore, FIS is proper to be used for measuring the appropriateness of Indonesian palm-oil-based sustainability indicators.

2. Methodology
This research was accomplished through three stages, namely preliminary research, appropriateness assessment and system validation. The preliminary research was conducted by reviewing bioenergy sustainability standards from various country and categorizing them by some aspects. In addition, we also determined the standards which contained the sustainability indicators that would be assessed their appropriateness with Indonesian palm-oil-based bioenergy. The determined standard was the one that internationally accepted, general for use, and it contained balanced proportion between environment, economic, and social aspects.

The assessment for the appropriateness of indicators was conducted using Mamdani fuzzy inference system (FIS) model towards the determined standard which was obtained after the preliminary research. The Mamdani FIS is a model which is able to be implemented into the input containing human linguistic variable. The output is in a fuzzy set[7]. The required steps to generate the output using Mamdani FIS model are determination of fuzzy set, application of implication function, composition of rules and defuzzification[8].

After that, a data analysis was conducted towards the output of the system generated by Matlab, so the appropriateness value of each indicator could be determined as well as the number of sustainability indicators which are appropriate to Indonesian palm-oil-based bioenergy. A validation process of the system was conducted in order to examine the accuracy of the system. This process was conducted by inputting a value into the system and comparing the output with the opinion from the expert. In this research, the system was using 81 cases. The accuracy calculation was performed with Equation 1 where X denotes number of case having the same result between system output and expert’s opinion and Y denotes number of total cases.

\[ \text{Accuracy} = \frac{X}{Y} \times 100\% \] (1)
3. Result and Discussion

3.1 Review of Global Bioenergy Sustainability Indicators

Sustainability becomes one of the important issue in the world. The development of various things is always linked to sustainability as it impacts towards the environment, society and economy. There were initiations that generate standards containing principles, criteria, and indicators about bioenergy sustainability. Those initiations are national, international, and multi-stakeholder initiation. Some of global standard regarding to bioenergy sustainability are Indonesian Sustainable Palm Oil Certification System (ISPO), International Sustainability & Carbon Certification (ISCC), Renewable Transport Fuel Obligation (RTFO), Global Bioenergy Partnership (GBEP), Roundtable on Sustainable Palm Oil (RSPO), and Roundtable on Sustainable Biomaterials (RSB). Each standard generally consists of the minimum requirements for biodiversity protection, reduction of gas house emission and other issues regarding to water, land, or social aspects.[9].

After the analysis was done for each of the standard, a review of a global bioenergy sustainability standard was performed by categorizing them into five groups, namely environment, social, economic, legality (documentation, legislations), and implementation (production activity, standard operational procedure or SOP, transparency). This review can be seen in table 1. Each of the standards has a tendency in particular group. Standards that have a tendency to the environment indicators are ISCC, RTFO, RSPO and RSB. ISPO contains more about legality, whereas GBEP has a balanced proportion between environment, economic and social.

| Sustainability standard | Scope | Number of indicator in principles or criteria | Number of indicators |
|-------------------------|-------|---------------------------------------------|---------------------|
| ISPO (Indonesian Sustainable Palm Oil)[10] | Plantation, plantation that produces palm oil | 42 | 30 | 2 | 46 | 13 | 133 |
| ISCC (International Sustainability and Carbon Certification)[11] | Bio- and renewable energy based supply chain and raw material | 56 | 34 | - | 2 | 3 | 95 |
| RTFO (Renewable Transport Fuel Obligation)[12] | Reduction of GHG emission from fuel used on-road and off-road | 24 | 18 | - | - | - | 42 |
| GBEP (Global Bioenergy Partnership)[13] | The relation between production activity and the use of palm-oil based bioenergy in a sustainable development context | 8 | 8 | 8 | - | - | 24 |
| RSPO (Roundtable Sustainable of Palm Oil) | Plantation, industries producing palm-oil-based fuel, producer of palm-oil derivate products | 62 | 51 | 2 | 14 | 9 | 138 |
| RSB (Roundtable on Sustainable Biofuel) | Production, utilization and transportation of renewable energy based on biomass | 19 | 13 | - | 1 | 3 | 36 |

Notes: environment (En), social (S), economic (E), legality (L), implementation (Im)
Based on the review, we found that GBEP is the suitable standards for undergoing appropriateness assessment for Indonesian palm-oil-based bioenergy. Several factors that support GBEP to be the most suitable standards for Indonesian are its international recognition and general use, having a balanced proportion between environment, economic, and social aspects as well as its inclusion of the overall bioenergy production activity from the cultivation of palm oil to the use of bioenergy. GBEP has 24 indicators which consists of 8 environmental indicators, 8 economic indicators and 8 social indicators. Sustainability indicators of GBEP can be seen in table 2.

Table 2. Sustainability indicators of GBEP

| Environment                                            | Social                                           | Economic                                    |
|--------------------------------------------------------|--------------------------------------------------|---------------------------------------------|
| 1. Life–cycle GHG Emissions                            | 9. Allocation and tenure of land for bioenergy    | 17. Productivity                            |
| 2. Soil quality                                        | 10. Price and supply of a national food basket    | 18. Net energy balance                      |
| 3. Harvest levels of wood resources                    | 11. Change in income                             | 19. Gross value added                       |
| 4. Emissions of non-GHG air pollutants, including air toxins | 12. Jobs in the bioenergy sector                  | 20. Change in consumption of fossil fuels and traditional use of biomass |
| 5. Water use and efficiency                            | 13. Change in unpaid time spent by women and children collecting biomass | 21. Training and requalification of the workforce |
| 6. Water quality                                       | 14. Bioenergy used to expand access to modern energy services | 22. Energy diversity                       |
| 7. Biological diversity in the landscape               | 15. Change in mortality and burden of disease attributable to indoor smoke | 23. Infrastructure and logistics for distribution of bioenergy |
| 8. Land use and land-use change related to bioenergy feedstock production | 16. Incidence of occupational injury, illness, and fatalities | 24. Capacity and flexibility of use of bioenergy |

Source: The Global Bioenergy Partnership Sustainability Indicators for Bioenergy First Edition[13]

3.2 Design and Documentation of the System

Mamdani FIS model used to assess the appropriateness of Indonesian palm-oil-based bioenergy sustainability indicators. The defuzzification method that used was Mean of Maximum (MOM). The steps to generate the output using Mamdani FIS model are fuzzification, application of implication, composition of rules, and defuzzification [8].

3.2.1 Fuzzification

Fuzzification is process to determine the fuzzy set that contains membership functions and domains [14]. Before the fuzzification, we need to determine the input and output variables of the system. The input variable is the assessment criteria of the appropriateness of Indonesian palm-oil-based bioenergy. The criteria are the relevant (targeted of its usefulness), user utility, reliability (provable in a scientific ways), and measurability (data is available, easy to collect, and always updated)[15]. Meanwhile, the output variables is the appropriateness of palm-oil-based bioenergy indicators. The relationship between the input and output variables can be seen at figure 2.
Figure 1. Dependency diagram of the input and output system

The input variables had three fuzzy sets, namely low, moderate, and high or less easy, quite easy, and easy. It had trapezoidal and triangular types of membership function curve. The output variables had three fuzzy sets, namely less appropriate, quite appropriate, and appropriate. It also had trapezoidal and triangular types of membership function curve. The sets of input and output variables can be seen in table 3.

Table 3. The set of input and output variables system

| Function | Name of variables | Notation | Fuzzy set | Type of curve | Domain | Range |
|----------|-------------------|----------|-----------|--------------|--------|-------|
| Input    | Relevant          | RL       | Low       | Trapezium    | [0,4]  |       |
|          |                   |          | Moderate   | Triangle     | [3,7]  | [0,10]|
|          |                   |          | High      | Trapezium    | [6,10] |
| User Utility | Less easy       | LE       | Trapezium  | [0,4]       |        |
|          |                   | Quite easy | Triangle | [3,7]  |        |
|          |                   | Easy     | Trapezium  | [6,10]      |        |
| Reliability | Low             | L        | Trapezium  | [0,4]       |        |
|          |                   | Moderate  | Triangle   | [3,7]  | [0,10]|
|          |                   | High     | Trapezium  | [6,10]      |        |
| Measurability | Less easy       | LE       | Trapezium  | [0,4]       |        |
|          |                   | Quite easy | Triangle | [3,7]  | [0,10]|
|          |                   | Easy     | Trapezium  | [6,10]      |        |
| Output   | Appropriateness   | AP       | Less appropriate | Trapezium | [0,4]  |        |
|          |                   |          | Quite appropriate | Triangle | [3,7]  | [0,10]|
|          |                   |          | Appropriate  | Trapezium  | [6,10] |        |

This system only used two types of membership function, namely trapezium and triangle. The membership function of the system can be seen in figure 2.
Fuzification of relevant input

\[ \mu_L[x] = \begin{cases} 0; & x \geq 4 \\ 1; & 0 \leq x \leq 2 \\ \frac{(4 - x)}{(4 - 2)}; & 2 < x < 4 \\ 0; & x \leq 3 \text{ or } x \geq 7 \end{cases} \]  

\[ \mu_M[x] = \begin{cases} \frac{(x - 3)}{(5 - 3)}; & 3 < x < 5 \\ 1; & x = 5 \\ \frac{(7 - x)}{(7 - 5)}; & 5 \leq x < 7 \\ 0; & x \leq 6 \end{cases} \]  

\[ \mu_H[x] = \begin{cases} 1; & 8 \leq x \leq 10 \\ \frac{(x - 6)}{(8 - 6)}; & 6 < x < 8 \end{cases} \]

Membership function for each fuzzy set of relevant input can be written as in the equation below:

Figure 2. Membership function for relevant input

Fuzification of user utility input

\[ \mu_L[x] = \begin{cases} 0; & x \geq 4 \\ 1; & 0 \leq x \leq 2 \\ \frac{(4 - x)}{(4 - 2)}; & 2 < x < 4 \\ 0; & x \leq 3 \text{ or } x \geq 7 \end{cases} \]  

\[ \mu_M[x] = \begin{cases} \frac{(x - 3)}{(5 - 3)}; & 3 < x < 5 \\ 1; & x = 5 \\ \frac{(7 - x)}{(7 - 5)}; & 5 \leq x < 7 \\ 0; & x \leq 6 \end{cases} \]  

\[ \mu_H[x] = \begin{cases} 1; & 8 \leq x \leq 10 \\ \frac{(x - 6)}{(8 - 6)}; & 6 < x < 8 \end{cases} \]

Figure 3. Membership function for user utility input
Membership function for each fuzzy set of user utility input can be written as in the equation below:

\[ \mu_{LE}[x] = \begin{cases} 
0; & x \geq 4 \\
1; & 0 \leq x \leq 2 \\
\frac{(4 - x)}{(4 - 2)}; & 2 < x < 4 \\
\end{cases} \]  

(5)

\[ \mu_{QE}[x] = \begin{cases} 
0; & x \leq 3 \text{ or } x \geq 7 \\
\frac{(x - 3)}{(5 - 3)}; & 3 < x < 5 \\
1; & x = 5 \\
\frac{(7 - x)}{(7 - 5)}; & 5 < x < 7 \\
\end{cases} \]  

(6)

\[ \mu_{E}[x] = \begin{cases} 
0; & x \leq 6 \\
1; & 8 \leq x \leq 10 \\
\frac{(x - 6)}{(8 - 6)}; & 6 < x < 8 \\
\end{cases} \]  

(7)

Fuzification of reliability input

![Membership function for reliability input](image)

**Figure 4.** Membership function for reliability input
Membership function for each fuzzy set of reliability input can be written as in the equation below:

\[
\mu_L[x] = \begin{cases} 
0; & x \geq 4 \\
1; & 0 \leq x \leq 2 \\
\frac{4 - x}{4 - 2}; & 2 < x < 4 \\
0; & x \leq 3 \text{ or } x \geq 7 
\end{cases} 
\]  

(8)

\[
\mu_M[x] = \begin{cases} 
\frac{x - 3}{5 - 3}; & 3 < x < 5 \\
1; & x = 5 \\
\frac{7 - x}{7 - 5}; & 5 \leq x < 7 
\end{cases} 
\]  

(9)

\[
\mu_H[x] = \begin{cases} 
0; & x \leq 6 \\
1; & 8 \leq x \leq 10 \\
\frac{x - 6}{8 - 6}; & 6 < x < 8 
\end{cases} 
\]  

(10)

Fuzification of measurability input

![Figure 5. Membership function for measurability input](image)

Figure 5. Membership function for measurability input
Membership function for each fuzzy set of measurability input can be written as in the equation below:

\[ \mu_{LE}[x] = \begin{cases} 
0; & x \geq 4 \\
1; & 0 \leq x \leq 2 \\
(4-x)/(4-2); & 2 < x < 4 \\
\end{cases} \quad (11) \]

\[ \mu_{GE}[x] = \begin{cases} 
0; & x \leq 3 \text{ or } x \geq 7 \\
(x-3)/(5-3); & 3 < x < 5 \\
1; & x = 5 \\
(7-x)/(7-5); & 5 \leq x < 7 \\
\end{cases} \quad (12) \]

\[ \mu_{E}[x] = \begin{cases} 
0; & x \leq 6 \\
1; & 8 \leq x \leq 10 \\
(x-6)/(8-6); & 6 < x < 8 \\
\end{cases} \quad (13) \]

Fuzification of appropriateness output

Figure 6. Membership function for appropriateness output
Membership function for each fuzzy set of the appropriateness output can be written as in the equation below:

\[
\mu_{LA}[x] = \begin{cases} 
0; & x \geq 4 \\
1; & 0 \leq x \leq 2 \\
(4 - x) / (4 - 2); & 2 < x < 4 \\
0; & x \leq 3 \text{ or } x \geq 7 
\end{cases} 
\]

\[
\mu_{QA}[x] = \begin{cases} 
(x - 3) / (5 - 3); & 3 \leq x < 5 \\
1; & x = 5 \\
(7 - x) / (7 - 5); & 5 \leq x < 7 \\
0; & x \leq 6 
\end{cases} 
\]

\[
\mu_{A}[x] = \begin{cases} 
1; & 8 \leq x \leq 10 \\
(x - 6) / (8 - 6); & 6 < x < 8 
\end{cases} 
\]

(14)

(15)

(16)

3.2.2 Application of implication

The application of implication was used min implication. The determination of implication area was performed by generating rules. The number of rules generated from the four fuzzy sets are 81 rules. Before application of implication, it’s important to determine the membership degree for each input value. The determination of membership degree for each input can obtained by inputting the input value into membership function. After the membership degree was obtained, application of implication function was performed by taking the minimum value of membership degree from each rule. An example of the application of implication can be seen in the description below. This example was performed for indicator numbered 16 in the 41th rule with input values are 5.47 (RL), 5.6 (UT), 5.8 (RB), 5.87 (MU).

\[
\alpha_{R41} = \min [\mu_{RL}[5.47] \land \mu_{UT}[5.6] \land \mu_{RB}[5.8] \land \mu_{MU}[5.87]]
\]

\[
= \min (0.765; 0.7; 0.6; 0.565)
\]

\[
= 0.565
\]

The implication area of the system in Matlab can be seen in figure 7 at the red box outline area.
3.2.3 Composition of rules

Composition of rules are aggregation of some rules. In this system, composition of rules was performed by taking the maximum membership degree between rules using OR operator. In general, composition between rules can be written as in equation (17) where $\mu_{sf}[x_i]$ denotes the value of fuzzy membership and $\mu_{kf}[x_i]$ denotes the value of fuzzy consequent membership.

$$
\mu_{sf}[x_i] \leftarrow \max (\mu_{sf}[x_i], \mu_{kf}[x_i])
$$

(17)

The example of rules composition that performed towards the indicator numbered 16 can be seen in the red marked area in figure 8.
3.2.4. Defuzification

Defuzification is a process that converts the output system into fuzzy set domain which the system had. Defuzification was performed using Mean of Maximum (MOM) model that takes average domains of maximum membership degree. For example, the indicator numbered 16 has maximum membership degree value at 0.565 in the 41st rule. After that, we determined which fuzzy set domain that had maximum membership degree at 0.565 by inputting it into membership function so that obtained two domains at 4.23 and 5.87. The determination process to obtain fuzzy set domain are in the description below.

\[
0.565 = \frac{x - 3}{2} \quad \frac{0.565}{2} = 7 - x
\]
\[
x = 4.23 \quad x = 5.87
\]

Defuzification was performed by averaging domain values that had maximum membership degree. The resulted output value for indicator numbered 16 from Matlab was 5 then translated into fuzzy set so that the output value means quite appropriate. The process of defuzification with MOM are in the description below.

\[
Z = \frac{4.23 + 5.87}{2} = \frac{10}{2} = 5
\]

3.3 Indonesian palm-oil-based bioenergy sustainability indicators

The determination process was performed using Mamdani fuzzy inference system (FIS) model. This process was performed by conducting appropriateness assessment for each indicator by the expert from Indonesian government (professional), practitioner (industrialist) and academic. This assessment was performed by filling the questionnaire. The results showed that there were 21 sustainability indicators which are appropriate for Indonesian palm-oil-based bioenergy. Those indicators consisted of 8 environmental indicators, 5 social indicators and 8 economic indicators. The appropriateness value for each indicator can be seen in table 4.

### Table 4. Results of data processing in the Mamdani FIS system

| No | Relevant | User Utility | Reliability | Measurability | Appropriateness |
|----|----------|--------------|-------------|---------------|-----------------|
| 1  | 9.53     | H            | 8.4         | E             | 8.07            | H               | 7.87            | E               | 8.95            | A               |
| 2  | 9.4      | H            | 8.27        | E             | 8.2            | H               | 7.73            | E               | 8.9            | A               |
| 3  | 8.07     | H            | 7.93        | E             | 7.73           | H               | 7.8             | E               | 8.9            | A               |
| 4  | 8.6      | H            | 8           | E             | 7.13           | H               | 7.4             | E               | 8.6            | A               |
| 5  | 9.07     | H            | 8.6         | E             | 8.73           | H               | 7.6             | E               | 8.8            | A               |
| 6  | 8.73     | H            | 8.13        | E             | 8              | H               | 7.27            | E               | 8.65           | A               |
| 7  | 8.13     | H            | 6.87        | E             | 6.67           | H               | 5.87            | QE              | 8.35           | A               |
| 8  | 8.4      | H            | 7.47        | E             | 7.33           | H               | 7.2             | E               | 8.6            | A               |
| 9  | 8.8      | H            | 7.67        | E             | 7.67           | H               | 7.4             | E               | 8.7            | A               |
| 10 | 7.8      | H            | 7.53        | E             | 7.6            | H               | 7.47            | E               | 8.75           | A               |
| 11 | 8.93     | H            | 8.53        | E             | 7.93           | H               | 8.07            | E               | 9             | A               |
| 12 | 8.73     | H            | 8.13        | E             | 7.8            | H               | 7.73            | E               | 8.9            | A               |
| 13 | 6.53     | H            | 6.6         | E             | 6.27           | H               | 6.13            | QE              | 5             | QA              |
| 14 | 8.93     | H            | 8.27        | E             | 8              | H               | 7.33            | QE              | 8.7            | A               |
| 15 | 5.87     | M            | 6           | QE            | 5.93           | M               | 5.93            | QE              | 5             | QA              |
| 16 | 5.47     | M            | 5.6         | QE            | 5.8            | M               | 5.87            | QE              | 5             | QA              |
| 17 | 8.8      | H            | 8.4         | E             | 8.4            | H               | 7.6             | E               | 8.8            | A               |
| 18 | 8.33     | H            | 7.33        | E             | 7.93           | H               | 7.27            | E               | 8.65           | A               |
| 19 | 8.2      | H            | 7.6         | E             | 7.47           | H               | 7.27            | E               | 8.65           | A               |
| 20 | 8.73     | H            | 8.13        | E             | 7.93           | H               | 7.67            | E               | 8.85           | A               |
| 21 | 7.87     | H            | 7.6         | E             | 7.47           | H               | 7.27            | E               | 8.65           | A               |
| 22 | 8.87     | H            | 7.87        | E             | 8              | H               | 7.27            | E               | 8.65           | A               |
Indicator 13, 15, and 16 which were not selected for Indonesian palm-oil-based bioenergy because based on its generated value by Mamdani FIS model, they were not appropriate with the condition of Indonesia and in the case of palm-oil-based bioenergy. The appropriate indicators that generated by Mamdani FIS model can be seen in table 5.

**Table 5. Bioenergy sustainability indicators based on Mamdani FIS method**

| Environment | Social | Economic |
|-------------|--------|----------|
| 1. Life–cycle GHG Emissions | 9. Allocation and tenure of land for new bioenergy production | 14. Productivity |
| 2. Soil quality | 10. Price and supply of a national food basket | 15. Net energy balance |
| 3. Harvest levels of wood resources | 11. Change in income | 16. Gross value added |
| 4. Emissions of non-GHG air pollutants, including air toxics | 12. Jobs in the bioenergy sector | 17. Change in consumption of fossil fuels and traditional use of biomass |
| 5. Water use and efficiency | 13. Bioenergy used to expand access to modern energy services | 18. Training and re-qualification of the workforce |
| 6. Water quality | | 19. Energy diversity |
| 7. Biological diversity in the landscape | | 20. Infrastructure and logistics for distribution of bioenergy |
| 8. Land use and land-use change related to biodiesel feedstock production | | 21. Capacity and flexibility of use of bioenergy |

Based on this model, there were 21 indicators which were appropriate for Indonesian palm-oil-based bioenergy industry. After that, a validation process was conducted by inputting a value into the system and comparing the output with expert’s opinion. There were 81 cases that were tested into this system and the accuracy was 85%. The system validation can be seen in table 6.
Table 6. System validation of the Mamdani FIS model

| No | Relevant | User Utility | Reliability | Measurability | Appropriateness (output of system) | Appropriateness (expert’s opinion) |
|----|----------|--------------|-------------|---------------|-----------------------------------|-----------------------------------|
| 1  | 2        | L            | 4           | LE            | 3.5                               | L                                 |
| 2  | 0        | L            | 1.5         | LE            | 4                                 | L                                 |
| 3  | 1.25     | L            | 3           | LE            | 2.25                              | L                                 |
| 4  | 4        | L            | 2.6         | LE            | 7                                 | M                                 |
| 5  | 1.5      | L            | 4           | LE            | 6.5                               | M                                 |
| 6  | 3.5      | L            | 3.9         | LE            | 5                                 | M                                 |
| 7  | 0        | L            | 3           | LE            | 9.25                              | H                                 |
| 8  | 2.5      | L            | 2.9         | LE            | 10                                | H                                 |
| 9  | 4        | L            | 0           | LE            | 8                                 | H                                 |
| 10 | 2.25     | L            | 7           | QE            | 2                                 | L                                 |
| 80 | 10       | H            | 10          | E             | 9.25                              | H                                 |
| 81 | 7        | H            | 10          | E             | 10                                | H                                 |

4. Conclusion
Sustainability becomes one of the important issue in the world. The development of various things is always linked to sustainability as it impacts towards the environment, society, and economy. Many countries have made standards which contain principles, criteria and indicators about bioenergy. The review of global sustainability indicators related to bioenergy revealed that International Sustainability & Carbon Certification (ISCC) has 95 indicators that focus on environment, Renewable Transport Fuel Obligation (RTFO) has 42 indicators that focus on the environment, Global Bioenergy Partnership (GBEP) has 24 indicators that focus on environment, economic, and social, Roundtable on Sustainable Palm Oil (RSPO) has 138 indicators that focus on environment, and Roundtable on Sustainable Biomaterials (RSB) has 36 indicators that focus on environment.

The Indonesian palm-oil-based sustainability indicators were obtained by assessing the appropriateness of the indicators using Mamdani FIS method towards Global Bioenergy Partnership (GBEP) standards for each indicator. The number of sustainability indicators for Indonesian palm-oil-based bioenergy with Mamdani FIS model was 21 indicators, consisting 8 environmental indicators, 5 social indicators, and 8 economic indicators. The system had an accuracy of 85%.

5. Recommendation
The system can be further developed by adding other inputs that support the appropriateness assessment criteria for Indonesian palm-oil-based bioenergy sustainability. Moreover, the rules combination can be changed to get the best combination rules and also by adding the number of fuzzy sets so that the accuracy of the system can be improved.

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