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# Sustainability index assessment of palm oil-based bioenergy in Indonesia

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## ABSTRACT

This paper reported the status of Indonesian sustainable palm oil-based bioenergy development. The sustainability assessment of palm oil-based bioenergy has become a critical issue due to its positive impact to the foreign exchange savings in Indonesia. Otherwise, several negative appraisements, especially in the social and environment aspect have caused disapproval of Indonesian bioenergy products in the global energy market, as well as in the European Union. The status of sustainability which is described by the sustainability index has been obtained from the multidimensional scaling analysis. This study was conducted through several stages, including: (1) Determining the sustainability indicators which are most appropriate for palm oil-based bioenergy in Indonesia, and also a recommendation in the establishment of Indonesia Bioenergy Sustainability Indicators. (2) Assessing the sustainability index through the multidimensional scaling analysis. The focus group discussion has recommended 10 sustainability indicators. Indonesia Bioenergy Sustainability Indicators was divided into 2 indicators on the environmental aspects, 3 indicators on the social aspects and 5 indicators on the economic aspects. Meanwhile, on the environmental aspect (waste management and clean production) was subdivided into 3 sub indicators. The results of the sustainability assessment have obtained the average score index of 35.02% which indicates that the Indonesian sustainability status of the palm oil based bioenergy is still low (less sustainable). This research also showed the level of sustainability of each aspects, which is the score index of the economic aspects of 38.03% (less sustainable), the social aspect of 16.07% (unsustainable) and environmental aspect of 50.97% (sustained moderate). In conclusion, these sustainability index are expected to be useful as the foundation of determining the best strategy for future Indonesian bioenergy development.

## 1. Introduction

Agricultural sector in Indonesia plays an important role in raising rural livelihood, as it is becoming the main source of national income (Alwarritzi et al., 2015). Palm oil has not only become the most potential agricultural commodity to produce alternative energy sources, such as for fuel in industry and transportation, power generation and household (Hambali et al., 2010). Its abundant availability also causes the palm oil to be an important source to enhance economic level of Indonesian society (Joni et al., 2010). It has become evident commodity due to its potential use as bioenergy resources which generally available in form of liquid such as biodiesel or bioethanol, gaseous or known as biogas and solid form like pellet, briquette or bio briquette (Soerawidjaja, 2011). It is widely used for producing heat, electricity as well as fuel (William et al., 2015).

Indonesia has become the largest palm oil producer all over the world. The production area was distributed about 95% in Sumatra and Kalimantan, it was increasingly cultivated in peat lands (Afriyanti et al., 2016). The increment in land occurred significantly during 1990–2010, from 3.5 million ha to 13.1 million ha with a growth rate of 7% per year (Agus et al., 2013). Food and Agriculture Organization (FAO) also noted that total palm oil production of

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Indonesia in 2014 reached 29.27 million metric tons (MMT), that is much higher than Malaysia (19.67 MMT) (FAO, 2016). Totally, both Indonesia and Malaysia are able to produce more than 85% of the world's palm oil (Jayed et al., 2011; Fitzherbert et al., 2008).

Currently palm oil development as the bioenergy resource feedstock is still a debate. Although for some Asian countries like Indonesia palm oil is a source of economic improvement, but this step was socially and environmentally considered highly controversial (Oosterveer, 2015). To expand the agricultural area from the global land for the energy enhancement are considered as one of the causes of greenhouse gas emissions that increasing the earth-surface temperature (Havlik et al., 2011). Otherwise, the expansion of land through logging activities has caused biodiversity effect, the loss of organic matter in the soil (Gamborg et al., 2012; Schmidt et al., 2011).).

Further impacts as a result of land conversion practices for palm oil plantation development are the increase in $CO_2$ emissions (Lee et al., 2014; Mukherjee and Sovacool, 2014; Abood et al., 2015), loss of biodiversity (Lee et al., 2011; Peñarandaa et al., 2015) as well as reduced carbon content resulting in decreased soil quality (Goh et al., 2016). The largest source of $CO_2$ emissions originated from a land use trajectory that caused undisturbed forest to be degraded to disturbed forest and then to shrub land, presumably the result of logging and wildfire. Emissions from was estimated at 267 Tg $CO_2$ $yr^{-1}$ between 2000 and 2005 (39% of the total) and 285 Tg $CO_2$ $yr^{-1}$ between 2006 and 2009/2010 (36% of the total) (Agus et al., 2013). The use of various fertilizers in oil palm plantation was also responsible for soil fauna feeding activity (Tao et al., 2016). If the implementation of the bioenergy mandatory policy is not accompanied by an increase in land productivity, the target of fulfilling biofuel needs by 2030 is predicted to require 35.2 million hectares of oil palm plantations. Land development is also expected to generate 5.41 Gg t of CO2 emissions (Papilo and Hartrisari, 2016).

Land is essentially also needed for various other aspects such as agriculture as an effort to meet the needs of food, forest protection and human inhabitation. Development of bioenergy through the utilization of agricultural products is also considered as one of the threats to food security (Popp et al., 2014; Scarlat et al., 2015).

According to Caroko et al. (2011), development of palm oil-based bioenergy was considered as a remarkable factor of environmental degradation and social impacts in the community. As a bioenergy material, development of palm oil plantations through direct or indirect activities of land-use change is a major cause of deforestation (Gunarso et al., 2013; Abood et al., 2015). From 2000 to 2010, the development of palm oil plantations in Indonesia caused the loss of 4744 ha of Mangrove forest, 0.38 million ha of peat land forest, 0.29 million ha of medium land forest and nearly 1000 ha of forest in mountainous areas (Lee et al., 2014). Even deforestation of primary forests occurring in Indonesia (0.84 Mha) by 2012 ~~is~~ was much higher than Brazil (0.46 Mha) (Margono et al., 2014).

Furthermore, development of palm oil-based bioenergy has also induced the social conflicts. The land expansion and clearance reduced availability of land for settlements and other plantations. In contrast land prices is increased and even triggered conflicts over land tenure rights in communities (Obidzinski et al., 2012). Land ownership closely linked with the above land sharing arrangements are issues pertaining to land ownership that are often shown to undermine local tenure systems in palm oil plantations. Traditional land tenure institutions are often not legitimized by central or provincial governments that view customary lands as open for commercial production (Mukherjee and Sovacool, 2014).

In terms of interest, the social gap is often experienced by palm oil farmers who work independently without getting the support of plantation companies. Small farmers generally get less attention than the farmers who become the partners of the company (Alwarritzi et al., 2015). Meanwhile, an independent smallholder household receives lower gross monthly incomes compared to the scheme and managed smallholder households, whereby the independent smallholders received the lowest gross monthly income from oil palm cultivation (Lee et al., 2013). Therefore, to reduce the negative impacts and trade-offs of oil palm palm-oil plantations and to enhance their economic potential, government decision makers need to restrict the use of forested land for plantation development, enforce existing regulations on concession allocation and environmental management, to improve monitoring of labor practices, to recognize traditional land use rights, and make land transfer agreements by involving customary land more transparent and legally binding (Obidzinski et al., 2012).

Various negative allegations addressed to the development of oil palm plantations in Indonesia. This condition generated a reaction and became an important concern of the Indonesian Government. The development of palm oil-based bioenergy especially biodiesel, is one of the efforts to increase the income and enhance the country's economy. Through the provision of a blending mandatory policy between biofuels and fossil fuels, it is economically expected to be a source of economic income in the form of additional foreign exchange (Dirtjen EBTKE, 2015).

In an effort to respond to various criticisms that have been addressed by various parties to the Indonesian's development of palm oil-based bioenergy, the government is committed to taking various actions. It begin with policy decisions that prioritizing sustainability principles until its implementation of best practices in plantation management and bioenergy development. Therefore, as bargaining effort, the Indonesian Government initiated to establish a set of sustainability standards which serve the guidelines for sustainable bioenergy development. Furthermore, by establishing the sustainability standards appropriate to Indonesia's needs and conditions, it will be a guide to estimate the sustainability status of bioenergy development in Indonesia including palm oil-based bioenergy. The important questions that will be answered in this research include: 1) what are the indicators that best suit the potential condition and development of bioenergy in Indonesia? and 2) how the sustainability status of palm oil based bioenergy development is based on sustainability index?

Therefore, this research aims to identify and obtain some of the most appropriate indicators to be applied for bioenergy development in Indonesia. Through mapping of existing sustainability standards, and gaining expert's opinion from focus group discussion (FGD) activities, bioenergy sustainability indicators in Indonesia (IBSI) has been recommended (Hambali et al., 2017). Furthermore, IBSI is used as a reference in estimating the sustainability index that describes the sustainability status of palm oil based bioenergy development.

## 2. Methodology

### 2.1. Research framework

FAO has been focusing a pilot test project on sustainability of bioenergy development in Indonesia from 2012 to 2014. The project adopted Global Bioenergy Partnership (GBEP) standard consisting of 3 aspects and 24 indicators of sustainability. The targeted areas are North Sumatra, Riau and West Kalimantan, which are productive areas of palm oil in Indonesia (FAO, 2014). In the study, the value of each indicator was obtained for all the observed areas.

However, the limitations in the FAO study are the absence of aggregate value that is applicable for determining the sustainability status of bioenergy development. Therefore, our research attempts to continue and complement the FAO study, by simultaneously assessing changes over the past 3 years since the pilot test project is implemented. Our research is expected to obtain an index value which is capable to describe the status of bioenergy sustainability development in Indonesia.

In this study, there are two targets has to be achieved, ***firstly***, to determine the sustainability indicators at IBSI. To obtain bioenergy development indicators in Indonesia, a series of activities have been conducted, including literature review of articles, regulations and documents containing various studies or indicators of bioenergy sustainability. Furthermore, through FGD activities, the literature study was discussed and submitted as a recommendation to the government on the indicators that are considered most needed in bioenergy development in Indonesia. The research framework is presented in Fig. 1.

The initiation of the establishment ~~an~~ of sustainability standard that is suitable to the Indonesia's bioenergy development is a series of activities initiated by reviewing the implementation of various global bioenergy sustainability standards as well as related studies that have been published in any international journals. Furthermore, to formulate and establish the IBSI, discussion and interview carried out by involving the bioenergy experts in Indonesia.

The literature review showed about 51 articles which related to this study. Many articles reported and discussed the sustainability issues related to the palm oil-based bioenergy and palm oil plantation. The topics discussed in the references are from numerous regions including Indonesia, Malaysia, and Thailand. Although over the last decade, research on sustainability of palm oil sustainability has increased (Hansen et al., 2015), however, for in-depth study in Indonesia was still very limited.

In addition, literature review also discussed previous sustainability standards established and used in some countries. Five sustainability standards reviewed include: 1) Roundtable on Sustainable Biomaterial (RSB·RSB); 2) Roundtable on Sustainable Palm Oil (RSPO); 3) Global Bioenergy Partnership (GBEP); 4) International Sustainability and Carbon Certification (ISCC); and 5) Indonesian Sustainable Palm Oil (ISPO). The literature resulted in basis and discussion substances in formulating indicators of bioenergy sustainability in Indonesia. To determine indicators, four times FGD activities have been conducted among various experts related to the bioenergy development in Indonesia.

***Secondly***, to assess the sustainability index of palm oil based bioenergy development in Indonesia. The following stages are carried out due to obtain the sustainability index: 1) to prepare the assessment questionnaire; 2) to set parameters or thresholds for each indicator; 3) to verify questionnaires to experts; 4) correcting the assessment questionnaire; 5) dissemination of instruments to experts; and 6) analysis. Finally, to obtain an index of sustainability of palm oil-based bioenergy development in Indonesia, were calculated using Multidimensional Scaling (MDS) method.

### 2.2. *Attribute and data requirement*

The indicators which is determined as an attributes are obtained from FGD, where GBEP standard is an agreed guideline as the basis for recommendation of Indonesia bioenergy sustainability indicators. GBEP has 24 sustainability indicators incorporated into 3 aspects of sustainability (economic, social and environmental) (GBEP, 2011). Meanwhile, the parameters and thresholds determination of each sustainability indicator is referred to the results of the pilot test conducted by FAO in 2012–2014 (FAO, 2014). The threshold of each indicator, being an assessment parameter in this study (Table 2).

FGD has been carried out by involving various bioenergy experts in Indonesia and it has summarized 10 sustainability indicators as given by Fig. 2.

By adopting and modified from Rapfish Analysis (Pitcher and Preikshot, 2001), we conducted Rapid Appraisal for Palm Oil-base Bioenergy (*Rap-Pobio*) to assess the sustainability index of palm oil-base bioenergy development in Indonesia. The research instruments with the attributes and assessment scales are given in Table 1.

### 2.3. *Multidimensional Scaling(MDS) method*

Multidimensional Scaling (MDS) has been widely used by researchers especially to determine the sustainability status of a development program. The parameters for determination of the status are sustainability index. MDS is a data analysis technique with statistical approach which is very useful to visualize dissimilarity from a study aspect, which is quantitatively and generally in 2 dimensions. Kruskal and Wish (1977); Borg and Groenen (2005); Kholil et al. (2015) state that MDS is a statistical analysis to determine the similarity and dissimilarity of variables described in geometric spaces. While to measure the relationship between objects, proximity is used which means the proximity of one object to

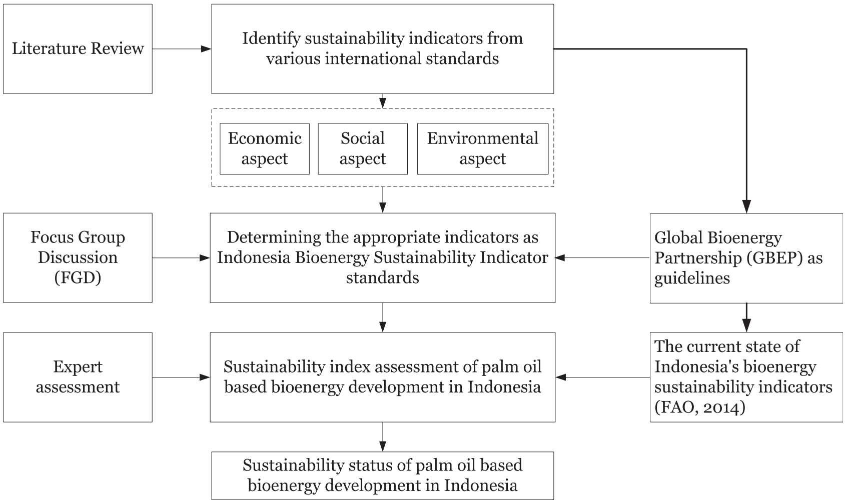


**Fig. 1.** Research framework.

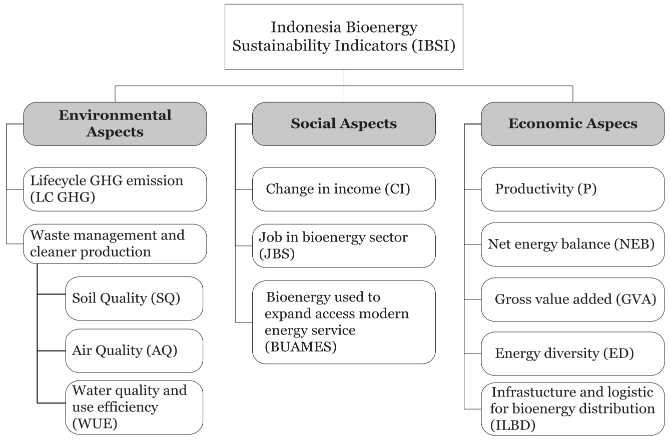


**Fig. 2.** Indonesia bioenergy sustainability indicators (IBSI) (Source: Hambali et al., 2017).

**Table 2**
Respondents of research.

| Profession | Number of experts | |
|---|---|---|
| | FGD participants | Sustainability index assessment |
| Government Officials | 4 | 1 |
| Officials at Bioenergy Company | 5 | 1 |
| Association members | 8 | 2 |
| Researchers of academician | 12 | 2 |
| Researchers of research center | 7 | 1 |
| Total of experts | 36 | 7 |

another.

In addition, the main function of MDS is to present objects visually based on various similarities. Furthermore, MDS is also useful for grouping objects that have similarities from some variables that are considered capable of grouping these objects (Wickelmaier, 2003; Jaya et al., 2013).

MDS has been used by Fisheries Center at University of British Columbia, Canada to develop Rapfish (rapid appraisal for fisheries) (Jaya et al., 2013; Kholil et al., 2015). Rapfish is a rapid assessment technique designed to enable a goal, transparency, multi-disciplinary evaluation, but it is not intended to replace conventional inventory valuations in the determination of a quota (Pitcher and Preikshot, 2001). Rapfish has more stable properties than multiple variable analysis methods such as factor analysis (Fauzi and Anna, 2005).

Rapfish has some advantages such as: 1) able to measure and describe the condition of sustainable resources in a place or region; 2) able to simply and comprehensively analyze all aspects of sustainability; 3) a multivariate method that can handle non-metric data; 4) multi-dimensional diversity can be projected in a simpler

**Table 1**
Indicators and parameters of sustainability assessment.

| Indicators for each aspect | Good | Bed | Scale and parameters |
|---|---|---|---|
| **A. Environmental** | | | |
| 1. Lifecycle GHG emission (LC GHG) | 3 | 0 | [0] Emission more than 150 g CO2eq/MJ; [1] Emission 140–150 g CO2eq/MJ; [2] Emission 50–140 g CO2eq/MJ; [3] Emission less than 50 g CO2eq/MJ |
| 2. Waste Management | | | |
| 2.1 Soil quality (SQ) | 3 | 0 | [0] SOC less than 1%; [1] SOC about 1%–5%; [2] SOC about 5%–10%; [3] SOC more than 10% |
| 2.2. Air quality (AQ) | 3 | 0 | [0] Emission more than 600 mg/MJ;<br>[1] Emission about 400 mg/MJ - 600 mg/MJ; [2] Emission about 200 mg/MJ - 400 mg/MJ; [3] Emission less than 200 mg/MJ |
| 2.3. Water quality and use efficiency (WUE) | 3 | 0 | [0] TPA more than 0,005% TARWR;<br>[1] TPA about 0,003% - 0,005% TARWR; [2]: TPA about 0,001% –0,003% TARWR; [3] TPA less than 0,001% TARWR |
| **B. Social** | | | |
| 1. Change in income (CI) | 3 | 0 | [0] Average income of labors involved in bioenergy development is below regional minimum rate in 2016; [1] Average income of labors involved in bioenergy development is same as regional minimum rate in 2016; [2] Average income of labors involved in bioenergy development is 2 times greater than regional minimum rate in 2016;<br>[3] Average income of labor involved in bioenergy development is 2 times greater than regional minimum rate in 2016, and compensation. |
| 2. Job in bioenergy sector (JBS) | 3 | 0 | [0] Opportunity for permanent workers is 20% of total available position;<br>[1] Opportunity for permanent workers is 20%–30% of total available position; [2] Opportunity for permanent workers is 30%–40%of total available position;<br>[3] Opportunity for permanent workers is more than 40% of total available position |
| 3. Bioenergy used to expand access modern energy service (BUAMES) | 3 | 0 | [0] Growth of installed PLTB less than 10% per year; [1] Growth of installed PLTB less than 10% per year about 10%–20% per year;<br>[2] Growth of installed PLTB less than 10% per year about 20%–30% per year; [3] Growth of installed PLTB less than 10% per year more than 30% per year |
| **C. Economic** | | | |
| 1. Productivity (P) | 3 | 0 | [0] Biodiesel production in 1 ton of palm oil less than 30.000 MJ/ton/year; [1] Biodiesel production in 1 ton of palm oil about 30.000–40.000 MJ/ton/year; [2] Biodiesel production in 1 ton of palm oil about 40.000–50.000 MJ/ton/year; [3] Biodiesel production in 1 ton of palm oil more than 50.000 MJ/ton/year |
| 2. Net energy balance (NEB) | 3 | 0 | [0] NER less than 4,0;<br>[1] NER about 4,0–5,0; [2] NER about 5,0–6,0; [3] NER more than 6,0 |
| 3. Gross value added (GVA) | 3 | 0 | [0] Gross value added for bioenergy less than 0,02% of national GDP; [1] Gross value added for bioenergy about 0,02% - 0,05% of national GDP; [2] Gross value added for bioenergy about 0,05% - 0,10% of national GDP; [3] Gross value added for bioenergy more than 0,10% of national GDP |
| 4. Energy diversity (ED) | 3 | 0 | [0] Herfindahl index less than 0,1 MJ bioenergy per year; [1] Herfindahl index about 0,1–0,5 MJ bioenergy per year; [2] Herfindahl index about 0,5–0,9 MJ bioenergy per year; [3] Herfindahl index is 1,0 MJ bioenergy per year |
| 5. Infrastructure and logistic for bioenergy distribution (ILBD) | 3 | 0 | [0] Road condition and capacity along bioenergy supply chain is not well supported; [1] Road condition and capacity along bioenergy supply chain is quite supported; [2] Road condition and capacity along bioenergy supply chain is well supported; [3] Road condition and capacity along bioenergy supply chain is strongly supported |

and easier to understand field; 5) able to serve as a tool for determining snapshots or preliminary analyzes to obtain a comprehensive picture of the status of resource sustainability; 6) providing researchers a lot of quantitative information from the resulting projection value; 7) able to be a reference to evaluate fishery condition of a region quickly; 8) able to bridge the limitations of data and research that are still minimal with the aim to make an assessment; and 9). The analysis results can be replicated and objective numerically (Nijkamp, 1980; Fauzi and Anna, 2002). This Following steps are required to the MDS implementation (Kholil et al., 2015):

a. Determination of aspects and indicators is conducted by discussion with expertise, valuation and scoring. The score is provided in ordinal scale ranging from 0 (low) to 3 (high) in accordance with characters of measured indicators.
b. Ordination of MDS to leverage factors from attributes based on Root Mean Square (RMS) in X and Y axis. Refer to Alder et al. (2000), ordination is based on Euclidean distance (d), which is able to formulated in n-dimension space as follow:

$$d = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \tag{1}$$

The value is then approximated by regression of distance ($d_{ij}$) from point 1 to point j to initial point ($\delta_{ij}$) by using this formula:

$$d_{ij} = \alpha + \beta\delta_{ij} + \varepsilon \tag{2}$$

This formula is regressed using ASCAL method, which optimizes squared distance ($d_{ij}$) over initial point ($O_{ijk}$) in 3-dimensional space (i, j, k), expressed as *S-Stress* ($S$) formula:

$$S = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left|\frac{\sum_i\sum_j\left(d_{ijk}^2 - O_{ijk}^2\right)^2}{\sum_i\sum_j O_{ijk}^2}\right|} \tag{3}$$

To obtain good accuracy of the analysis, after ordination, *Goodness of fit* in MDS is determined based on *S-Stress* which is calculated from S and $R^2$. Iteration can be stopped if $R^2$ value is approximately 1. Lower stress value demonstrates a good fit, while higher S value indicates the poor fit. The Stress value should be less than 0.25 which indicates an acceptable research analysis (Alder et al., 2000).

c. Analysis of sensitivity (leverage) and uncertainty using Monte Carlo method to understand effect of error in scoring. Estimation of error is performed in confidence interval of 95%. Analysis of sensitivity is needed to observe the most sensitive indicator providing contribution to sustainability index. It is carried out by observing ordination changes at absence of some indicator. Effects of each indicator cause changes in root mean square (RMS) ordination. Higher value of RMS changes means higher contribution of the attribute in determining sustainability index, vice versa (Kavanagh and Pitcher, 2004). The analysis steps and valuation of sustainability index using MDS is presented in Fig. 3.

### 2.4. Weights measurement method

Weighting is aimed to determine the priorities of each sustainability aspect. This weighting result will be multiplied by the sustainability index value obtained through MDS method. In this study, the weight of each aspect was calculated using the Eckenrode Method (Eckenrode, 1965). The concept of weighting is to change the sequence into values, where the first order with the highest (value) and second order with the lower (value) level. The weight ($W_e$) value can be calculated by the formulation as follow:

$$W_e = \sum_{j=1}^{n}\lambda_{ej} \Big/ \sum_{e=1}^{k}\lambda_{ej}\sum_{j=1}^{n}e_{ej} \tag{4}$$

where: $\lambda_{ej}$ as objective value to λ by expert j, and n as number of experts.

### 2.5. Respondent of research

Our research involves some experts from government, enterprise, researchers of academician, researchers of a research center, and practitioners in a related association of bioenergy in Indonesia. In general, the experts that serve as respondent in our study have more 10 years-experience in their expertise area. To determine indicator of Indonesia bioenergy sustainability, FGD was conducted in four times by involving 36 experts. While, to offer assessment of bioenergy sustainability index involved 7 experts. Specifically, the experts came from some fields and institutions, including: 1) government representatives such as the Ministry of Energy and Mineral Resources and Ministry of Agriculture; 2) associations related

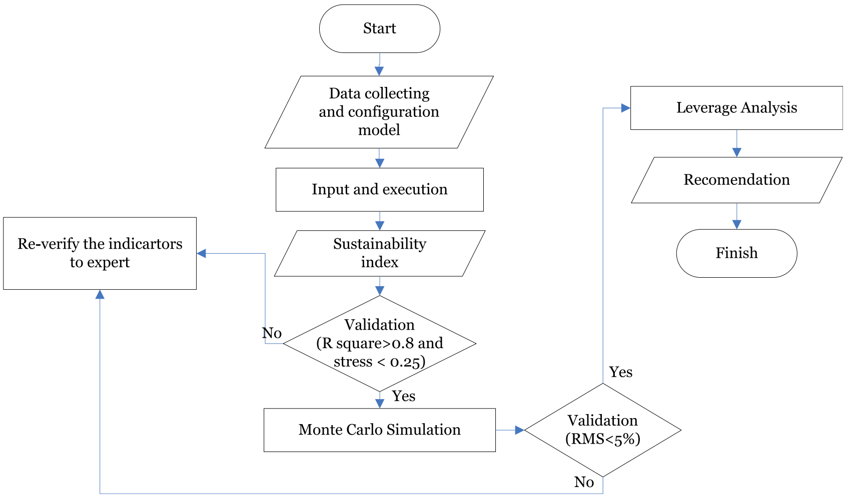


**Fig. 3.** Method of MDS

to the development and utilization of bioenergy such as association of Indonesian biofuel producers, Indonesian Palm Oil Association (IPOA), Association of bioenergy experts in Indonesia and association of Indonesian oil palm community; 3) representatives from other certification bodies such as ISPO; 4) expert from research centers, researchers and academicians. Table 2, presents distribution of our respondents.

## 3. Results

### 3.1. Progress of Indonesia bioenergy sustainability indicators (IBSI)

In recent years, there have been many initiatives for the establishment of bioenergy sustainability standards by several countries in the region such as European Union, joint initiation among international organizations, multi-stakeholders as well as initiation of each country. Several countries that are keen to develop bioenergy sustainability standards include Netherlands, England, Germany, Sweden, United States, Brazil and Indonesia. Meanwhile, international agencies that actively involved in the development of bioenergy sustainability standards are Food and Agriculture Organization (FAO), Organization for Economic Co-operation and Development (OECD), G8+5, International Energy Agency (IEA), International Finance Corporation (IFC), United Nations Environment Programmed (UNEP) and International Standard Organization (ISO) (Efryomson, 2012). Efryomson (2012) and Lima (2014) have identified that there have been 27 international sustainability standard was established in the world.

Some indicators and standards for development of sustainable bioenergy are generally produced according to general view of existing conditions. Certain indicators are sometimes less appropriate to be implemented in a country, such as Indonesia which relies more on palm oil as a source of bioenergy raw materials. Based on Dale (2013), many indicators focus on the management practices although knowledge of best practices that support sustainability efforts is still very limited. In addition, some indicators provide further impacts due to too many existing indicators that are difficult to be quantified, too wide in scope and even costly.

Some sustainability standards may have very diverse indicators, some of which are not directly related to the sustainability concepts. This makes the sustainability assessment obscure (Hayashi et al., 2014). Therefore, adjustment or arrangement of more appropriate standard for each country is required.

Global Bioenergy Partnership (GBEP) is one of the sustainability standards that consider looks at all three aspects in a balanced way. GBEP has equally divided sustainability standards into three equally social, economic, and environmental aspects. A total of 24 indicators are have been established, which consist of economic, social and environmental aspects. In each aspect, 8 indicators are have been set for each aspect (GBEP, 2011).

GBEP is considered to have advantages and suitability for the purposes of bioenergy development in Indonesia, among which GBEP already has fairly clear indicators with measurable parameters. This is particularly important to estimate the sustainability status shown in the form of a sustainability index. In addition, GBEP has a number of indicators that are balanced for all three aspects of sustainability, which consists of 8 indicators on economic aspects, 8 indicators on social aspects and 8 indicators on environmental aspects. Meanwhile, other sustainability standards generally more concerned on environmental aspects or aspects related to best practice management, especially for the management of plantations as sources of bioenergy.

Based on various considerations, all of participant of FGD have agreed and set 10 indicators of Indonesia's bioenergy sustainability. The indicators are divided into 2 indicators on environmental aspects, 3 indicators on social aspects and 5 indicators on economic aspects. In the environmental aspect, waste management and cleaner production indicators are divided into 3 sub indicators, consisting of soil quality, water quality and water quality and use efficiency. The proposed indicators for Indonesia bioenergy sustainability are then summarized in Table 3.

### 3.2. Description and measurement parameters of IBSI

In practical level particularly for assessing the sustainability index of bioenergy development, it is necessary to clarify the description and parameters of each sustainability indicators. Indonesia bioenergy sustainability indicators, which are adopted from GBEP, have explained the descriptions and parameters of each indicator, as summarized in Tables 4–6.

### 3.3. Sustainability index assessment of palm oil-based bioenergy in Indonesia

The assessment sustainability index of palm oil-based bioenergy in Indonesia, was involved 7 respondents from various fields and institution. Aggregation scores on the assessment of the respondents were determined by mode method. The score of respondents assessment on each indicator presented on the diagram as in Fig. 4.

To calculate the sustainability index and sensitive indicator related to bioenergy development in Indonesia, Rapid Appraisal for Palm Oil-base Bioenergy (*Rap-Pobio*) and Leverage analysis were conducted. The Following points are given to show the results of assessment of sustainability index for 3 aspects of environmental, social and economy. The sustainability index and leverage analysis result on each aspect can be seen in Figs. 5–7.

The assessment of sustainability index of Indonesia bioenergy development was carried out for all three aspects. The sustainability status of Indonesia bioenergy development can be determined using the average sustainability index of three aspects assessed. The average sustainability index for three aspects of sustainability was 35.02%, indicating that, overall, the sustainability status of bioenergy development in Indonesia is at a less sustainable level. Fig. 8 shows the average sustainability index based on the three aspects of sustainability (environmental, social and economic).

### 3.4. Validation of sustainability index assessment

Assessment of sustainability index using MDS method was performed at 2 stages. First, validation of sustainability index

**Table 3**
Sustainability indicators in IBSI.

| Sustainability aspects | Indicators number | Indicators of each aspects |
|---|---|---|
| Environmental | 1 | *Life −cycle GHG Emissions* |
| | 2 | *Waste management and cleaner production (soil, air, and water quality &use efficiency)* |
| Social | 3 | *Impact of Change in income* |
| | 4 | *Jobs in the bioenergy sector* |
| | 5 | *Bioenergy used to expand access modern energy service* |
| Economic | 6 | *Productivity* |
| | 7 | *Net energy balance* |
| | 8 | *Gross value added* |
| | 9 | *Energy diversity* |
| | 10 | *Infrastructure and logistics for distribution of bioenergy* |

(Sources: Hambali et al., 2017)

**Table 4**
Description and parameters of sustainability indicators for environmental aspects in IBSI.

| Indicators | Description | Parameter |
|---|---|---|
| 1. Life −cycle Gas House Glasses (GHG) Emissions (LC GHG) | Lifecycle greenhouse gas emissions from bioenergy production and use, as per the methodology chosen nationally or at community level, and reported using the GBEP Common Methodological Framework for GHG Lifecycle Analysis of Bioenergy. | Grams of $CO_2$ equivalent per mega joule. |
| 2. Waste Management and Clean Production<br>(soil, air and water quality & efficiency) | **2.1 Soil Quality (SQ)**<br>Percentage of land for which soil quality, in particular in terms of soil organic carbon, is maintained or improved out of total land on which bioenergy feedstock is cultivated or harvested. | Percentage. |
| | **2.2 Air Quality (AQ):**<br>Emissions of non-GHG air pollutants, including air toxics produced from:<br>• Bioenergy feedstock production.<br>• Processing,<br>• Transport of feedstock, intermediate products and end products, and<br>• Use and in comparison with other energy sources | Emissions of PM2.5, PM10, NOX, $SO_2$ and other pollutants can be measured and reported in the following ways as is most relevant to the feedstock, mode of processing, transportation and use:<br>• mg/ha, mg/MJ, and as a percentage<br>• mg/m3 or ppm<br>• mg/MJ |
| | **2.3 Water Quality and Use Efficiency (WUE)**<br>• Water withdrawn from nationally-determined watershed(s) for the production and processing of bioenergy feedstock, expressed.<br>• As the percentage of total actual renewable water resources (TARWR).<br>• As the percentage of total annual water withdrawals (TAWW), disaggregated into renewable and non-renewable water sources.<br>• Volume of water withdrawn from nationally-determined watershed(s) used for the production and processing of bioenergy feedstock per unit of bioenergy output, disaggregated into renewable and non-renewable water sources. | • Percentage<br>• $m^3$/MJ or $m^3$/kWh; $m^3$/ha or $m^3$/ton for feedstock production phase if considered separately. |

(Sources: Hambali et al., 2017; GBEP, 2011)

**Table 5**
Description and parameters of sustainability indicators for social aspects in IBSI.

| Indicators | Description | Parameter |
|---|---|---|
| 1. Impact of Change in income (CI) | Contribution of bioenergy production to income improvement. | • Wages in the bioenergy sector compared with other sectors<br>• Net income from the sale, barter with own-consumption including feed stocks by self-employed households |
| 2. Jobs in the bioenergy sector (JBS) | Net job creation as a result of bioenergy production and use:<br>• Total.<br>• Disaggregated by skilled/unskilled.<br>• Disaggregated by indefinite/temporary. | • Total number of jobs and percentage of worker that appropriate with age rule<br>• Total number of job in relation to comparable sectors |
| 3. Bioenergy used to expand access modern energy service (BUAMES) | • Total amount and percentage of increased access to modern energy services gained through modern bioenergy that measured in terms of energy and numbers of household and business.<br>• Total number and percentage of household and business using bioenergy, disaggregated into modern bioenergy and traditional use of biomass. | • Percentages |

(Sources: Hambali et al., 2017; GBEP, 2011)

**Table 6**
Description and parameters of sustainability indicators for economic aspects in IBSI.

| Indicators | Description | Parameter |
|---|---|---|
| 1. Productivity (P) | This indicator is primarily related to the theme of resource availability and use, efficiencies in bioenergy production, processing, and distribution. | The number of output from a production process per unit of input. |
| 2. Net energy balance (NEB) | Production of bioenergy requires energy as an input at different steps of the value chain. | The net energy ratio (i.e. ratio of energy output to total energy input). |
| 3. Gross value added (GVA) | The indicator shows the size of the contribution of the bioenergy sector to the national economy. | GDP per unit of bioenergy. |
| 4. Energy diversity (ED) | • This indicator refers primarily to the theme of Energy security or Diversification of sources and supply.<br>• Change in diversity of total primary energy supply (TPES) due to bioenergy. | Percentages. |
| 5. Infrastructure and logistics for distribution of bioenergy (ILBD) | Number and capacity of routes for critical distribution systems, along with an assessment of the proportion of the bioenergy associated with each. | Number of bioenergy distribution routes are utilizing water and road transport (vessel, truck). |

(Sources: Hambali et al., 2017; GBEP, 2011) assessment for each aspect of sustainability. At this stage, the feasibility of the assessment results is determined by Stress and $R^2$ value. Validation of sustainability index assessment of Stress and $R^2$ is a value to determine the condition of goodness of fits, which is a parameter indicating the representation of real data (Alder et al., 2000). Stress value which is less than 0.25 and $R^2$ that is greater than 0.80 indicates that the results of the sustainability index assessment are valid (Pitcher and Preikshot, 2001). The stress and $R^2$ values for all three aspects are given in Table 7.

It can be seen clearly that all three aspects have stress value < 0.25 and $R^2 > 0.80$. These parameters indicated that the sustainability index for all three aspects is capable to explain the real conditions (Alder et al., 2000).

Second, validation based on the difference between the sustainability index of each aspect and analysis result using Monte Carlo Simulation (at confidence interval of 95%). We found that sustainability index assessment is considered as feasible if the

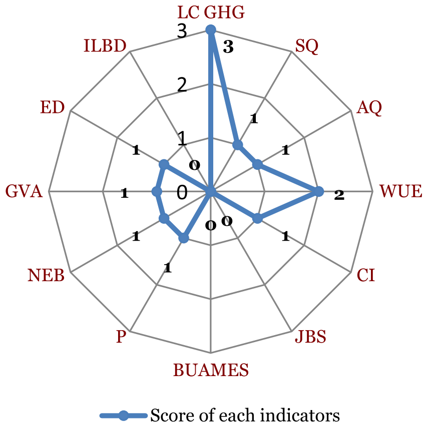
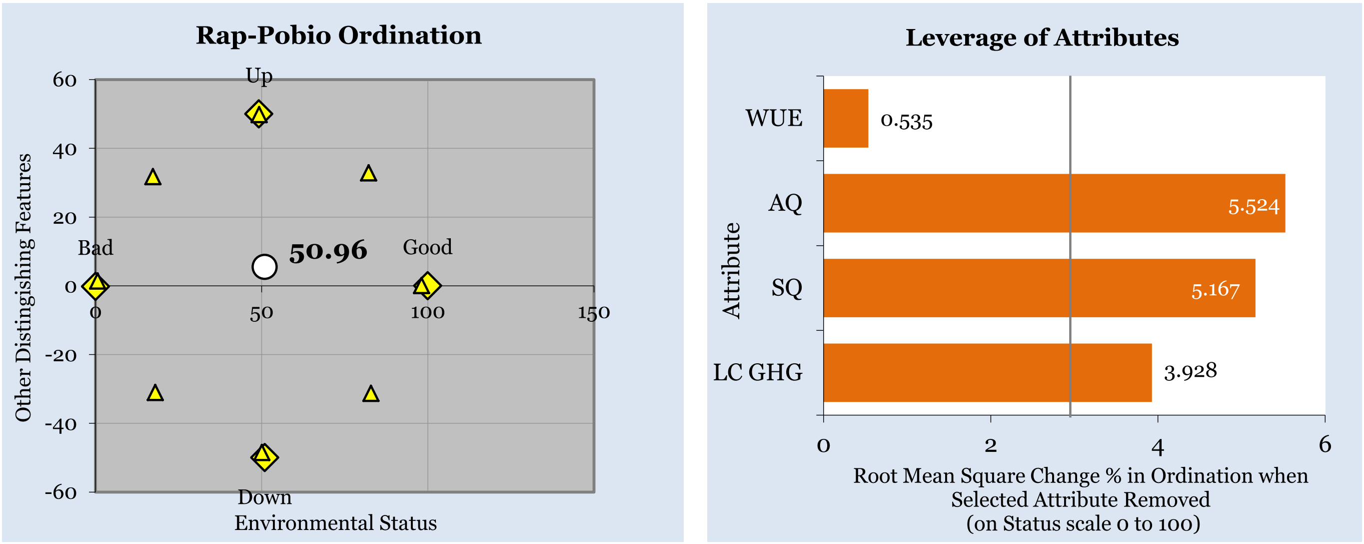
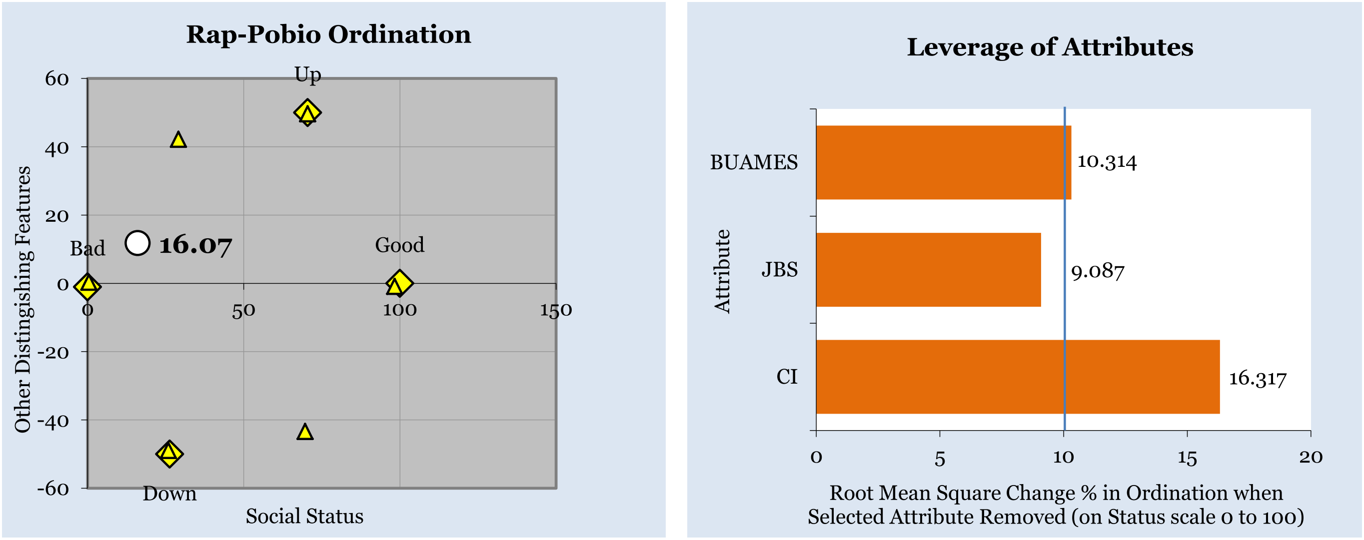


**Fig. 4.** Scores of respondent's assessment.



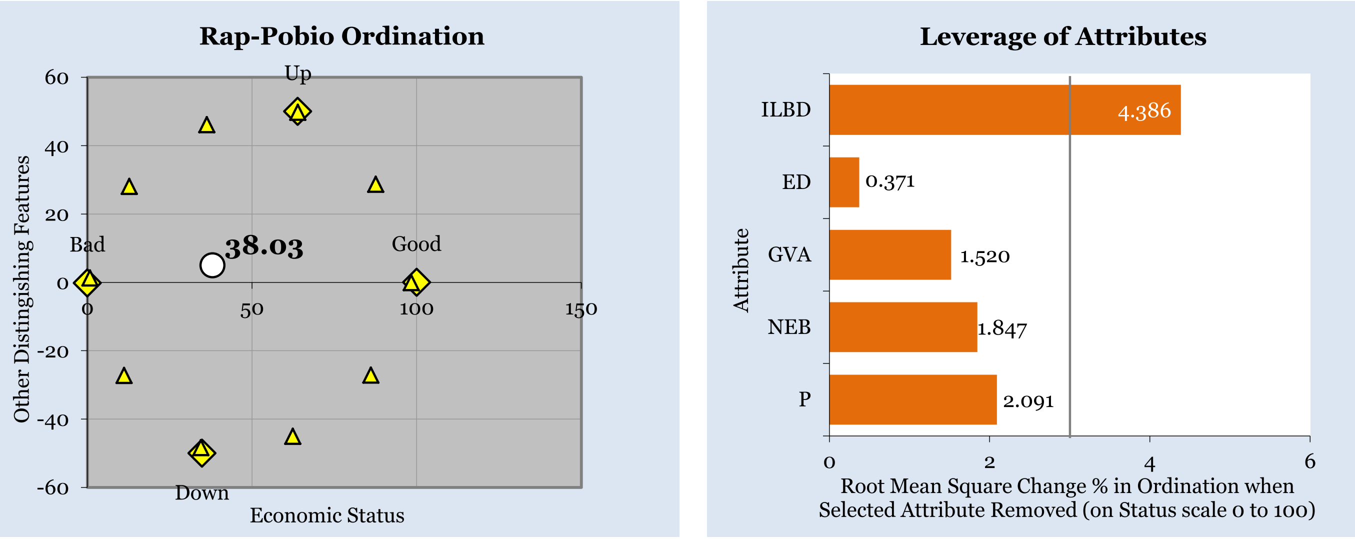
(a) (b)

**Fig. 5.** [a] Sustainability index and status of Indonesia bioenergy development in term of environmental aspect, [b] Sensitive factors affecting sustainability of environmental aspect.



(a) (b)

**Fig. 6.** [a] Sustainability index and status of Indonesia bioenergy development in term of social aspect, [b] Sensitive factors affecting sustainability of social aspect.



(a) (b)

**Fig. 7.** [a] Sustainability index and status of Indonesia bioenergy development in term of economic aspect, [b] Sensitive factors affecting sustainability of economic aspect.

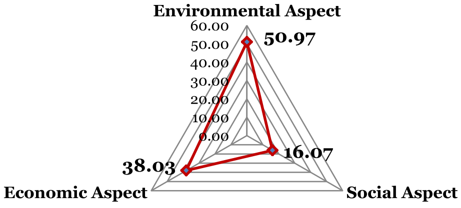


**Fig. 8.** Kite diagram of Indonesia bioenergy sustainability status.

difference between the sustainability index and the simulation analysis result is not more than 5%. The simulation results and the difference between the two analyzes are presented in Table 8.

Table 8 demonstrates that error rates for all three aspects of sustainability are very low (<5%). This parameter explains that the results of the assessment index of sustainability with Rap-Pobio have a good degree of accuracy (Kavanagh and Pitcher, 2004).

### 3.5. Sustainability index by priority

This study also estimates the weight of each aspects. Weight measurement aims to obtain a more objective index value according to the interests of palm oil-based bioenergy development in Indonesia today. The results of the sustainability index assessment based on the priority weighting shown in Table 9.

**Table 7**
Stress value and $R^2$ of sustainability index assessment.

| Aspects | Parameters | | Note |
|---|---|---|---|
| | Stress (<0.25) | $R^2$ (>0.80) | |
| Environmental | 0.169 | 0.924 | Valid |
| Social | 0.167 | 0.929 | Valid |
| Economic | 0.165 | 0.933 | Valid |

**Table 8**
Sustainability index by MDS and errors in simulation of Monte Carlo.

| Aspects | Sustainability Index | | Errors (%) | Note |
|---|---|---|---|---|
| | MDS (%) | Monte Carlo (%) | | |
| Environmental | 50.97 | 50.16 | 0.81 | Valid |
| Social | 16.07 | 17.65 | 1.58 | Valid |
| Economic | 38.03 | 38.28 | 0,25 | Valid |
| **Average** | **35.02** | **35.36** | **0.88** | |

## 4. Discussions

### 4.1. Sustainability status of environmental aspect

This study completed the previous one conducted by FAO in 2014, which has the contribution to find aggregation value as sustainability index of bioenergy development in Indonesia, especially derived from palm oil commodity. Indonesian bioenergy experts have determined 10 sustainability indicators to find out the status of Indonesia's bioenergy sustainability, (3 sub indicators in waste management indicator) that are considered most appropriate. These indicators were obtained through in-depth studies of the related articles and sustainability standards that have been agreed by various countries and international institutions as well as intensive and focused discussions.

The assessment of the sustainability status of Indonesian bioenergy development in term of environmental aspect is based on expert assessment on the main indicators of lifecycle GHG emission (LC GHG), soil quality (SQ), water quality (WQ) and water use and efficiency (WUE). Expert assessment exhibited that the environmental sustainability index score was 50.96% (scale of 0–100) which indicates that the sustainability status is quite higher.

Furthermore, leverage analysis is useful for understanding sensitive indicators and it has a significant effect on improving the sustainability index of an aspect (Kavanagh and Pitcher, 2004). The results of leverage analysis (see Fig. 5b) showed that three of four indicators analyzed were sensitive that may affect sustainability of environmental aspect related to bioenergy development in Indonesia. The indicators were (1) WQ amount 5.524; (2) SQ am0unt 5.167; and (3) LC GHG amount 3.928. All three sensitive indicators highly determined the sustainability status of bioenergy development in Indonesia, especially according to the environmental aspect.

The declining quality of water and soil around palm oil plantations is generally caused by excessive use of chemical fertilizers. Based on a survey conducted by FAO (2014), it showed that nitrates

**Table 9**
Sustainability index by priority.

| Aspects | Aspects Weight (%) | Sustainability Index by MDS Analysis (%) | Sustainability Index by Priority (%) |
|---|---|---|---|
| Environmental | 37.05 | 50.97 | 19.11 |
| Social | 16.67 | 16.07 | 2.68 |
| Economic | 45.83 | 38.03 | 17.43 |
| **Total** | | | **39.22** |

and phosphate were the largest pollutants that pollute rivers around palm oil plantations. Even further, very high water pollution can also potentially degrade aquatic ecosystems (Peñarandaa et al., 2015). So protection of soil and water is one of the important aspects in assessing the sustainability of palm oil especially related to the environment. Three indicators related to water retreats include erosion risk, groundwater recharge potential, and water resource buffers (Gingold et al., 2012). The implementation of best practice in the management of the empty fruit bunches of oil palm plantations, is one precaution in maintaining the quality of the soil ecosystem and also contribute to the sustainability of oil palm plantations (Tao et al., 2016).

Associated with the SOC, referring to FAO elaborated that the SOC content in mineral soils in Indonesia is a great variability due to the complex soil mix of each region. Survey results in East Kalimantan and South Kalimantan indicated that the SOCs in palm oil plantations in both regions ranged from 1.43 percent to 7.34 percent (with a depth of 0–30 cm) (FAO, 2014).

Likewise, the GHG emissions, its greatest impact are due to land conversion to palm oil plantations. Land acquisition through the burning process carried out by palm oil plantations or the communities, has caused the impact of GHG emissions in Indonesia. Furthermore, land conversions have become widespread on carbon-rich lands (FAO, 2014; Agus et al., 2013). Compared to Gross Domestic Product (GDP), GHG emissions intensity excluding to land use charge and forestry in Indonesia is ranked fifth of others Asia countries after China, India, Thailand and Malaysia, with total GHG emissions predicted to reach 99 tCO2 eq/USD 100,000 (Lee et al., 2017).

As well as efforts to reduce the impact of GHG emissions, with the proper matching of technology and local conditions, and applying sustainability screening, positively, biofuels can make important contributions to reduce Life Cycle Assessment (LCA) GHG emissions globally (Joly et al., 2015). Methane recovery and composting (Chiew and Shimada, 2013), the second and third generation biofuel development (Popp et al., 2014), are the best technologies to reduce GHG emission. Implementation of best management practice (Djomo et al., 2015), and the National Biofuel Policy is also in line with the global efforts to reduce the greenhouse gasses (Abdullah et al., 2009).

### 4.2. *Sustainability status of social aspect*

Social aspect is related to the various impacts to the society as a result of bioenergy development activities in Indonesia. In this study, three indicators of sustainability related to social aspect were change in income, job in bioenergy sector, and bioenergy used to expand access of modern energy service. Rap-Pobio analysis demonstrated that sustainability index for social aspect was 16.07%, indicating that the social sustainability status was very low.

The result of leverage analysis for social aspect related to the bioenergy development in Indonesia has also been obtained. We found that two of three indicators that most influence the sustainability of bioenergy development in Indonesia were (1) change in income (CI) amount 16.317 and (2) bioenergy used to expand access modern energy service (BUAMES) amount 10.314. This result also indicated that changing conditions in these two indicators led to the significant effect on the sustainability status of bioenergy development.

To assess changes in income along the supply chain of palm oil-based bioenergy management is quite difficult. This is due to the difficulties of identifying the roles especially workers who are involved in supplying raw materials until bioenergy production. FAO (2014) findings on oil palm plantations in North Sumatra show that wages earned by plantation and feedstock processing workers are above national minimum wage standards. Search on the ground, also have found the wages paid to production workers to two fold of the national average wage for plant and machinery operators.

But it is also expected that the development of palm oil-based bioenergy will have a positive impact on the improvement of the surrounding community's economy. However, there is still a social gap for rural communities around oil palm plantations. Palm oil-based bioenergy development over the prosperity of the workers who are directly related to plantation and palm oil processing, but not for the people in the surrounding villages or smallholders farmer. Therefore, in meeting the principles of sustainability, socially it needs serious attention either by palm oil plantation and processing companies or by the Indonesian Government (Mukherjee and Sovacool, 2014). It is also expected that the plantation and bioenergy industries of oil palm can improve social facilities and provide employment opportunities that have a positive impact on change in income for the surrounding rural communities (Hirawan, 2011).

The development of bioenergy of palm oil has not had a positive impact on bioenergy used to expand access modern energy service. Based on FAO (2014), over the past decade, modern bioenergy did not have any role in the increase in access to modern energy services in Indonesia. Until 2015, the development of palm oil-based bioenergy for the provision of modern energy, whether in the form of biofuels or for electricity is still very low. Based on the data from the Ministry of Energy and Mineral Resources of Indonesia, the total potential of 12,654 MWe, no more than 5% has been utilized for the electricity (Dirtjen EBTKE, 2015). Various obstacles, ranging from policy level, institutional until ~~to~~ technological capabilities in that field has led to the development of palm oil-based bioenergy to improve bioenergy used to expand modern access energy service which is not so increased. Therefore, these conditions require the role and attention of all stakeholders, in accordance with the ability and their respective roles.

### 4.3. *Sustainability status of economic aspect*

The determination of the sustainability status of bioenergy development in Indonesia is also assessed on the economic aspect. To improve the competitiveness of palm oil based bioenergy industry, the Indonesian government has established industrial cluster programs in three areas, including Riau, North Sumatra and East Kalimantan provinces. This strategy has had a positive impact on the improvement of the four elements of competitiveness, particularly from agglomeration of companies, value added and value chain, and improvement of economic infrastructure (Papilo and Bantacut, 2016).

In this study, five important economic indicators are productivity, net energy balance, gross value added, energy diversity and infrastructure and logistic for bioenergy distribution. Rap-Pobio analysis demonstrated that the sustainability index for social aspect was 38.03% which means that the Indonesian bioenergy sustainability was still low in term of economic aspect.

The surprising results has emerge from 5 indicators on economic aspect, experts gave an assessment that infrastructure and logistic for bioenergy distribution (ILBD) is the most sensitive indicator related to the sustainability. Leverage analysis showed that the most influential indicators on economic aspects were ILBD, with a leverage value of 4.386. This result indicates that the changes in infrastructure and logistic conditions for bioenergy distribution have a meaningful impact on bioenergy development in Indonesia.

ILBD is generally associated with the road conditions that connecting between parts of the unit in the palm oil-based bioenergy supply chain. The condition of infrastructure is crucial in the smoothness of the distribution process from oil palm plantations to bioenergy industries based on palm oil.

In order to distribute each of its products, palm oil plantation and processing companies are mostly through major roads that have been built by the government. Specific roads built by private oil palm plantation companies, are limited only from the plantation area to the main road. Until now, road conditions in plantations area are still generally unpaved, but uses more economical materials such as sandy road, rocky road or gravel roads. While the highways that connect between distribution areas, generally paved with a good quality.

### 4.4. *Sustainability status of palm oil-based bioenergy development in Indonesia*

The determination of sustainability status is based on the sustainability index score that has been obtained. Jamaludin et al. (2018), has divided the score into five levels, consisting of excellent, good, fair, poor, and very poor. Meanwhile, Kavanagh and Pitcher (2004), have grouped them into 4 categories based on the obtained indexes. The four categories of sustainability status consist of: (1) unsustainable, if index ranges from 0.00 to 24.99; 2) less sustainable if the index ranges from 25.00 to 49.99; 3) is quite sustainable if the index ranges from 50.00 to 74.99; and 4) sustainable, if the index is more than 75.00.

This research has yielded the Indonesian bioenergy sustainability index of 35.02% based on MDS approach. It means that sustainability status of bioenergy development in Indonesia is less sustainable. Meanwhile, sustainability index for each aspect was 50.97% for environmental aspect (quite sustainable), 16.07% for social aspect (unsustainable) and 38.03% for economic aspect (less sustainable).

In this study, we are also completing the results of sustainability index estimation by involving the weighting values of each aspect. Based on the weight measurement using Eckenrode method, it has obtained the weight value for environmental, social and economic aspects of 37.05%, 16.67%, and 45.83% respectively. Based on the weight measurement, it can be seen clearly that the weight value of the economic aspect is higher than the environmental and social aspects. This indicates that experts perceive for currently the economic aspect is prioritized over the other two aspects. The calculation of these weights also affects the overall index value. However, the significant weight measurement causes the value of sustainability index to increase from 35.02% to 39.22%.

Our analysis also revealed that 6 of 10 indicators and 3 sub indicators that are highly sensitive to sustainability level such as 3 indicators on environmental aspect, 2 indicators on social aspect and 1 indicator on the economic aspect. For the environmental aspect, the ~~3~~ most three sensitive indicators were (1) water quality, (2) soil quality, and (3) GHG emission lifecycle. Meanwhile, 2 sensitive indicators on social aspect were (1) change in income and (2) bioenergy used to expand access modern energy service, and 1 sensitive indicator on economic aspect which is infrastructure and logistic for bioenergy distribution.

This study has several limitations, both in terms of scope on the aspects of the study and from accuracy in data acquisition. Some other important aspects, that need to be considered in assessing the sustainability of bioenergy, are including the political aspects and technological aspects. Political aspects are considered important because they are highly relevant to the government policies in supporting the bioenergy production, creating favorable conditions and markets such as subsidies, tax exemptions, consumption and blending mandatory of biofuel, and fossil fuel. Technological aspects should be relevant in the assessment of bioenergy sustainability, considering emerging technologies as a result of competition in first generation bioenergy development (Bautista et al., 2016).

Meanwhile, related to the data accuracy is not enough to rely on the secondary data that coming from a limited sources. Data needs to be more credible obtained from a clear and accountable sources.

## 5. Managerial implication

The development of palm oil-based bioenergy should be oriented to the sustainability principles by giving serious and balanced attention to the three main pillars, including economic, social and environmental aspects. The development of bioenergy which is more concerned with one aspect than other aspects will cause any other problems in the future. Therefore, the strategic steps are needed at each level of management, both within the scope of the organization and within the scope of government.

In addition, cooperation, coordination and synergy among all of stakeholders and related institutions are needed to develop and implement existing resource utilization and management programs, in order to meet the national energy needs that continue to increase through the sustainable use and development of bioenergy. Sustainable bioenergy development efforts also need to be demonstrated starting from policy formulation, program development planning, institutional governance, to the best practice management in their field.

## 6. Conclusions and recommendations

This study has recommended 10 indicators in 3 aspects that are considered appropriate for sustainable bioenergy development in Indonesia. In environmental aspect, 2 main indicators are Life cycle of GHG Emission and Waste Management and cleaner production. In addition there are 3 supporting indicators that are derived from soil quality, air quality and water quality and use efficiency. In social aspect, there are 3 important indicators such as change in income, job in bioenergy sector and bioenergy used to expand access modern energy service. While the economic aspect is divided into 5 indicators consisting of productivity, net energy balanced, gross value added, energy diversity, and infrastructure and logistics for distribution of bioenergy.

In general, the sustainability index of palm oil-based bioenergy development in Indonesia explains that the sustainability status is still low or less sustainable. From the three aspects point of view, the sustainability status for social aspects is still very low compared to the economic and environmental aspects. Currently the main priority of the Indonesian Government is more likely to lead the economic aspects.

Therefore, bioenergy development needs more balanced attention to the all three aspects and each indicator of sustainability. The economic results determined from the development of palm oil-based bioenergy, should be allocated and used for the improvement of environmental and social aspects. This concern needs to be demonstrated by every stakeholder at every strategic level, from policy formulation to the operational management in the field.

In future research, as an effort to increase the capability of the results in explaining the existing problems, it is necessary to obtain more accurate data through direct surveys of each bioenergy development activities. This study also needs to be continued for other potential sources of bioenergy raw materials in Indonesia. In addition, the scope of the study requires to be further expanded by involving other important aspects relevant to sustainable bioenergy development efforts. Some aspects that need to be studied are political aspect, technological aspect and institutional aspect.

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