An Intelligent Model for Industry's Sustainability Assessment

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Abstract

Sustainability issue in the industrial sector donates challenges to solve with the appropriate framework. The objective of the research was to develop an intelligent system to assess the industry's sustainability performance. A fuzzy inference system (FIS) approach was proposed to develop the model and infer sustainability performance with triple-bottom-line inputs. A dashboard was provided as the model prototype to quick monitoring the current Industry's sustainability performance. The result showed that th e fuzzy inference system enables to infer the overall sustainability performance, which was not further discussed in previous research. This research generated 125 rules with expert validations to infer the sustainability performance. The dashboard of the current Industry's sustainability performance can assist decision-makers with sustainability controlling and improvement. Model validations show that the model was valid to assess sustainability in the various industrial sector.

Keywords
Industry, Inference system, Intelligent, Sustainability, Triple-bottom-line.

1. Introduction
Industry's sustainability holds an important role to maintain business competitiveness in the industry 4.0 era. The sustainability performance of the industry captures multi-dimensional performance involve stakeholders and entities. As defined in previous research, sustainability must consider at least three dimensions, also known as triple-bottom-line. The triple bottom line is organized by economic, social, and environmental dimensions detailed in indicators to perform the current sustainability dimensions. The implementation of sustainability in the industrial sector is not only mandatory. Moreover, it potentially influences customer view and satisfaction (Ciasullo et al., 2017).

The industrial sector is required to consider sustainability in business activities. As announced by United Nations (UN), sustainability is the global agenda to be implemented in any countries and sectors (Johnston, 2016). The sustainability considerations and implementations for the Industrial sectors find the way in business competitiveness (Zhang et al., 2018). Previous research related to sustainability implementation have been adopted for various industrial sectors. Muhsin and Noguchi, 2018) applied sustainability assessment model to find industrial zones with constraint to minimize agricultural impact; Ahmad et al., (2019) found sustainability performance of the food industry using proposed method and recommends improvement strategy; and Wiryawan et al., (2020) assess the vegetable industry performance and maintain the sustainability. As we found in the literatures, sustainability is required to assess the current performance to deliver future improvement. Besides that, sustainability assessment is essential for the competitive advantages and delivers exact policy based on the current sustainability performance (Khan, 2020).

The sustainability assessment is a requirement to analyse industrial competitiveness and readiness to adopt Industry 4.0 era. Previous research in the sustainability assessment model proposed multi-dimensional scaling (Wiryawan et al., 2020), system dynamic (Hjorth and Bagheri, 2006; Jaya et al., 2013), data envelopment analysis (Qorri and Kraslawski, 2018), ecological footprint (Yakovleva Sarkis and Sloan, 2012), multi-criteria decision making (Muhsin et al., 2018) and machine learning (Asrol et al., 2021). The previous frameworks find disadvantages for the sustainability assessment in Industry. Most of the methods are required real-world data acquisition that should be prepared well to ensure the model are valid and verified. In this kind of constraint, a new approach in modelling the sustainability assessment is required.

In sustainability assessment, it must define dimensions and indicators to develop the model. Dimensions in sustainability mean the aspect of finding the performance, which is defined as economic, social, and environmental. The indicator describes the dimensions with specific units and benchmarks for the data acquisition process (Juwana Muttil and Perera, 2012). Research in sustainability assessment to define the indicators has largely applied as found in previous research (Asrol et al., 2021; Husada and Mulyana, 2020; Yakovleva et al., 2012). The indicators data and information are collected by field observations or expert assessment with rating.

On the other hand, there is a lack of analysis to aggregate the overall sustainability assessment using the dimensions performance value obtained from the indicators data and assessment. As we find in previous research, to aggregate the overall sustainability performance, scholars have proposed arithmetic mean of dimensions (Shamraiz Ahmad and Wong, 2019), multi-criteria decision analysis (Mohamadzadeh et al., 2020), analytical hierarchy process and probability approach (Muhsin et al., 2018; Papilo et al., 2018; Wiryawan et al., 2020). Upon the potential gap of the research opportunity, the model development focuses on sustainability assessment and aggregation, considering the dimensions.

To find the overall sustainability performance, some of aggregations method are potentially to proposed. Since the industry adoption of industry 4.0 approach, an intelligent approach is preferred to design in the model (Vinuesa et al., 2020). According to the sustainability data environments that uncertainty, vague and imprecision (Phillis et. al., 2017) and the requirement of qualitative and quantitative approach (Galal and Moneim, 2016; Popovic et al., 2018), authors proposed fuzzy model as the intelligent system approach. A Fuzzy Inference System (FIS) model is designed to aggregate the overall sustainability assessment based on dimensions performance. FIS can accommodate the constraints which largely discussed in (Ratnayake, 2014; Sabaghi et al., 2016).

1.1 Objectives

The objective of the research is to develop an intelligent system to aggregate sustainability performance for Industry. The rest of the paper is organized as follow: in section 2, the research framework is delivered. Section 3 discuss the intelligent model and the applications for related cases. Finally, section 4 delivers conclusions and potential further research.

2. Methods

The research framework is depicted in Figure 1. The framework captures the general works of the research. It is beginning with model development, data acquisition and dashboard design and application to assess and monitor the sustainability performance of the industry.

At the first stage of the research, the sustainability dimensions are defined. After that, a Fuzzy Inference System model is formulated based on the fuzzy system approach. In general, a Mamdani FIS is developed to infer sustainability performance due to its ability for complex assessment and achievable for human input characteristics (Mitsuishi and Shidama, 2009) that are required in sustainability assessment. In this phase, five stages will be obtained: crisp input, fuzzifications, fuzzy rule-based formulation, aggregation, defuzzification and finally, crisp output. The detail of the FIS model development is explored as follow:

2.1. Crisp input

The crisp inputs of the FIS model are the value of sustainability dimensions which units are in percent. The sustainability dimensions consider in this research are economic, social, environment as the triple bottom line of the sustainability. To test the model, the crisp input are obtained by Monte-Carlo technique which possible to generate precision data for model testing as explored in (Shamim Ahmad and Jamshed, 2015).

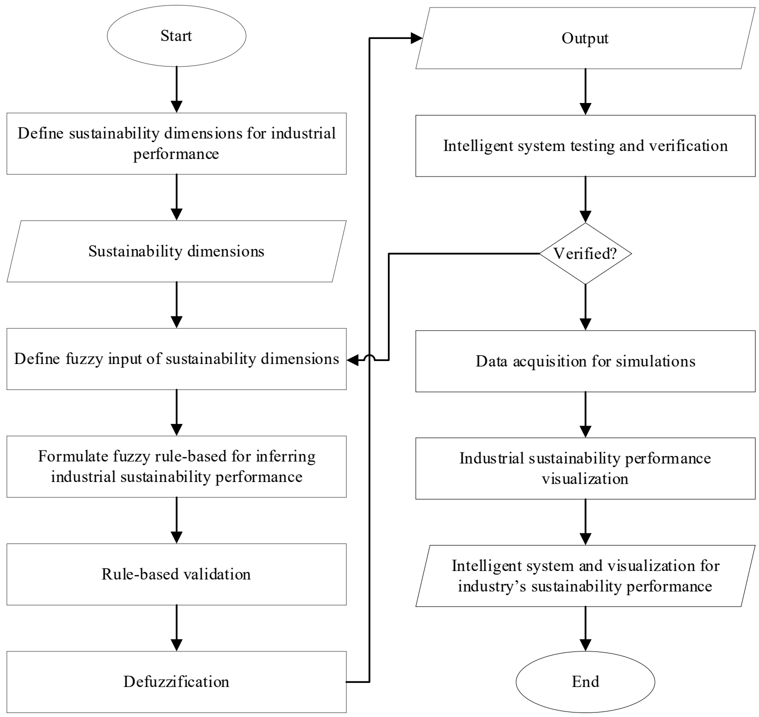


Figure 1 Research framework

2.2. Fuzzification

The fuzzification is a technique to transform input variable to fuzzy number. A membership function modeling is required for each input and output which in this model is organized by input and output of sustainability performance. This research adopts (Ahmad et al., 2019) to developed the linguistic label of the input variables while the output linguistic scale are refer to (Khan, 2020). A Triangular Fuzzy Number (TFN) is applied since the simplicity to accommodates opinion related to sustainability dimensions environment (Hemdi and Sharif, 2013).

To transform the real-data input, a membership function for TFN is required. Suppose that *a* > *b* > *c*, then a linguistic variable $\mu[x]$ in TFN model and the degree of membership function, are defined as Equation 1.

$$\mu[x] = \begin{cases} 0; & x \leq a \; or \; x \geq c \\ \dfrac{x-a}{b-a}; & a \leq x \leq b \\ \dfrac{c-x}{c-b}; & b \leq x \leq c \end{cases} \tag{1}$$

2.3. Fuzzy rules aggregation

Fuzzy rule-based is required to infer output with the specific variables input. The antecedent and consequent part organize a fuzzy rule. At the antecedent part, input variables are combined while consequent is the linguistic labels of output FIS model. Suppose that the number of linguistic labels as L and the number of the input variables as i, therefore, the number of the fuzzy rule to be developed is mentioned at Equation 2.

This research adopts Phillis et al. (Phillis et al., 2011) to generate the fuzzy rule based. While to validate the model, expert validation is proposed as will mentioned at the end of this part.

$$number\ of\ fuzzy\ rules = \prod_{i=1}^{n} L_i \quad (2)$$

2.4. Defuzzification model

Defuzzification is the final stage of the FIS model to transform the fuzzy number into crisp output and infer the solution. This research applies centroid defuzzification model which determines the crisp output at the center and height of the fuzzy rule combinations output. Suppose that Ni(x) as the aggregate value of membership functions and x as output variables, the defuzzification value using centroid method (X) is described at Equation 3.

$$X = \frac{\int N_i(x)x\ dx}{\int N_i(x)\ dx} \quad (3)$$

2.4. Defuzzification model

The model validation for an intelligent system in sustainability assessment is validated through the face validation technique as proposed in (Sargent, 2013). Experts are required to evaluate the dependent part of the developed fuzzy rule base. In case a group of experts are involved in validation, experts' opinions are required to be aggregated.

A FIS model has been proposed to design an intelligent model in sustainability assessment for Industry. In-brief, model and parameter to develop an intelligent model for inferring the industry's sustainability performance is stated in Table 1.

Table 1. FIS model and parameter for sustainability assessment

No	Model and parameter	Operator
1	Fuzzy inference model	Mamdani
2	Fuzzification model	*Triangular Fuzzy Number*
3	Operator	And
4	Implication model	Min
5	Aggregation model	Max
6	Defuzzification model	*Centroid*
7	Fuzzy rule-based generation	Adapted from Phillis *et al.* (Phillis et al., 2011)
8	Crisp input	Sustainability dimensions
9	Crisp output	Sustainability performance
10	Validation model	Expert Face validation with OWA

3. Results and Discussion

3.1 Sustainability for industry

The potential environmental impact of the industry sector in the business process leads the regulations to manage the issue. During operations, the business process of industrial sectors is provided high income to Gross Domestic Product (GDP) of a country and provide valuable products for communities. As the definition which is mentioned by Sukardi, (2011), Industry is a business process to produce a value added product from the raw materials with physical and chemical processes. In the remaining process to produce the product, Industry is potentially to generate the environmental impact. Further, the industrial sector may affect the social and economic impact, which is further known as the triple-bottom-line of sustainability.

In the further implementation of the industry 4.0 framework, the requirement of the implementation of the sustainability concept is very high (Evans and Taticchi, 2013). As aforementioned, the UN regulations have also supported the sustainability implementation and, in the meantime, developing countries will join the goal. In the downstream sector of the industry, consumer is also forcing the practitioners to provide a sustainable process and product. As a result, in the academic foundation and research in sustainability assessment and implementation has been largely proposed. Our previous research related to Industry's sustainability is found in the sugar industry using the Green Productivity Index (Asrol and Purba, 2021) and the assessment of the sustainability performance for the

Bioenergy Industry using support vector machine (Asrol et al., 2021). Scholars also proposed models to assess and improve the sustainability performance of the Industry, as we found in the palm oil industry (Papilo et al., 2018), construction and architecture (Sakina, 2018; Sujana, 2020; Wijaksono et al., 2018), food industry (Peano et al., 2015) and many others.

The development and the implementation of sustainability in Industry has found to reduce the environmental impact and assisting the adoption of industry 4.0 (Bonilla et al., 2018). In many applications, the sustainability assessment and improvement have also contributed to the industry's business process performance. In the further implementation of sustainability in Industry, a sustainability assessment is required to recommend a strategy in improvement (Asrol et al., 2021).

Regarding the sustainability assessment, the sustainability performance is generally organized by 3 main pillars of economic, social, and environmental dimensions as mentioned in (Ahmad and Wong, 2019; Papilo et al., 2018). The sustainability assessment model is required to assess the industrial performance in sustainability. This research develops an intelligent model to quickly assess the industry's performance in sustainability.

This research proposed economic, social, and environmental dimensions to assess the industry's sustainability performance. A Fuzzy Inference System (FIS) modelling is proposed as the framework to assess the performance. In a basic idea, the sustainability performance is evaluated through dimensions performance to encourage the overall industry' sustainability performance. Equation 4 describes the general model to evaluate the industry's sustainability performance. In the following sections, the model development is revealed.

$$\textit{Sustainability performance} = f\ (\textit{Economic, Social, Environmental}) \qquad (4)$$

3.2. Fuzzy Inference System modelling for an intelligent sustainability assessment at Industry

A Fuzzy Inference System (FIS) model required input and output variables to generate fuzzy rule-based and infer the output. Developing an intelligent model for sustainability assessment in Industry is providing a clear definitions that the performance status will be found through dimensions, economic, social and environment (Juwana et al., 2012). This research focus on the dimensions of value and performance as the input and the output is sustainability performance to address the general Industry's assessment model. Therefore, the general model of the intelligent model in sustainability's performance in Industry is depicted at Figure 2. A Triangular Fuzzy Number modelling is applied in the model due to its performance, since the model are organized by 3 inputs with 5 linguistic levels and generates 125 rule items.

Fuzzification is the first stage in FIS modelling. This model applies the TFN membership function for input variables developed in five linguistic scales, involving very low, low, medium, high, and very high. The TFN model of the input variables in 5 linguistic scales is showed at Equation 5-9. The input linguistic scale is adapted from Ahmad *et al.* (Ahmad et al., 2019). As an illustration of the linguistic labels and scales of the input and output model are depicted at Figure 3. Further, the TFN model for the output variables is showed at Equation 10-14. The fuzzy linguistic label for output model as sustainability status organized by not sustainable (NS), limited sustainable (LS), moderately sustainable (MS), sustainable (SB), and highly sustainable (HS) which are adapted from Khan, (2020).

$$\mu_{VeryLow}[x] = \begin{cases} 0; & x \leq 0 \text{ or } x \geq 30 \\ (30-x)/(30-0) & 0 \leq x \leq 30 \end{cases} \qquad (5)$$

$$\mu_{Low}[x] = \begin{cases} 0; & x \leq 10 \text{ or } x \geq 50 \\ (x-10)/(30-10); & 10 \leq x \leq 30 \\ (50-x)/(50-30) & 30 \leq x \leq 50 \end{cases} \qquad (6)$$

$$\mu_{Moderate}[x] = \begin{cases} 0; & x \leq 30 \text{ or } x \geq 70 \\ (x-30)/(50-30); & 30 \leq x \leq 50 \\ (70-x)/(70-50) & 50 \leq x \leq 70 \end{cases} \qquad (7)$$

$$\mu_{high}[x] = \begin{cases} 0; & x \leq 50 \text{ or } x \geq 90 \\ (x-50)/(70-50); & 50 \leq x \leq 70 \\ (90-x)/(90-70) & 70 \leq x \leq 90 \end{cases} \qquad (8)$$

$$\mu_{VeryHigh}[x] = \begin{cases} 0; & x \leq 70 \\ (x-70)/(1-70) & 70 \leq x \leq 100 \end{cases} \qquad (9)$$

$$\mu_{Unsustainable}[x] = \begin{cases} 0; & x \leq 0 \; or \; x \geq 30 \\ (30-x)/(30-10) & 0 \leq x \leq 30 \end{cases} \quad (10)$$

$$\mu_{LimitedSustaiable}[x] = \begin{cases} 0; & x \leq 10 \; or \; x \geq 50 \\ (x-10)/(30-10); & 10 \leq x \leq 30 \\ (50-x)/(50-30) & 30 \leq x \leq 50 \end{cases} \quad (11)$$

$$\mu_{ModeratelySustainable}[x] = \begin{cases} 0; & x \leq 30 \; or \; x \geq 70 \\ (x-30)/(50-30); & 30 \leq x \leq 50 \\ (70-x)/(70-50) & 50 \leq x \leq 70 \end{cases} \quad (12)$$

$$\mu_{Sustainable}[x] = \begin{cases} 0; & x \leq 50 \; or \; x \geq 90 \\ (x-50)/(70-50); & 50 \leq x \leq 70 \\ (90-x)/(90-70) & 70 \leq x \leq 90 \end{cases} \quad (13)$$

$$\mu_{HighlySustainable}[x] = \begin{cases} 0; & x \leq 70 \; or \; x \geq 90 \\ (x-70)/(100-70) & 70 \leq x \leq 100 \end{cases} \quad (14)$$

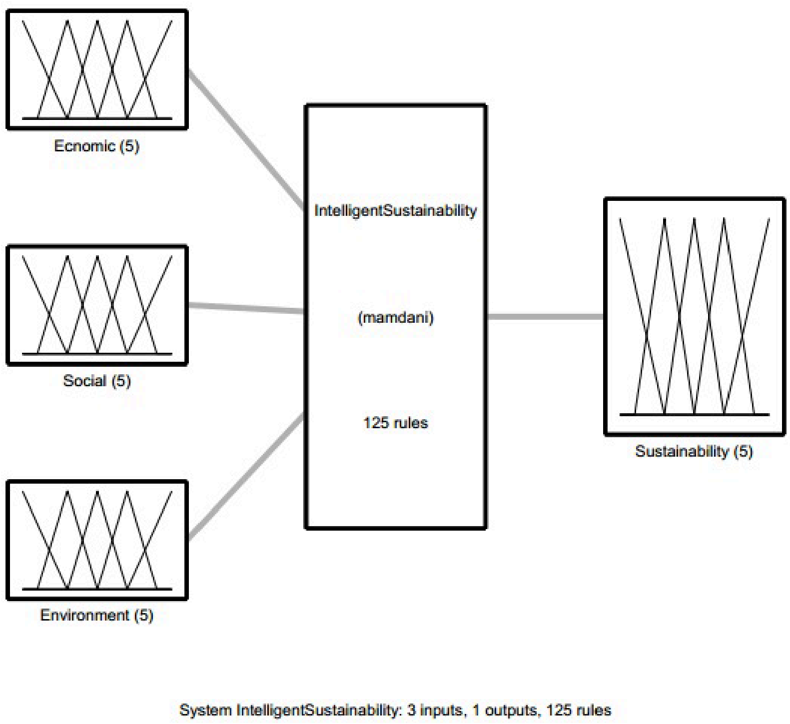
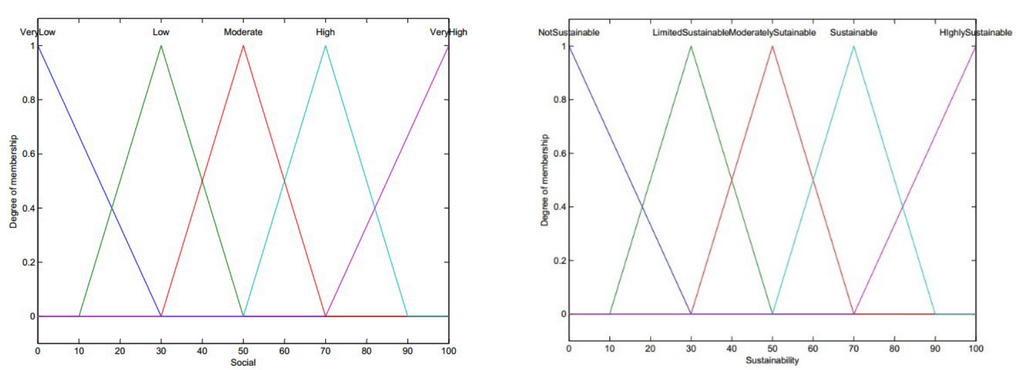


Figure 2. Intelligent model for sustainability assessment



(a) (b)

Figure 3. Linguistic scale and labels for (a) input and (b) output variables

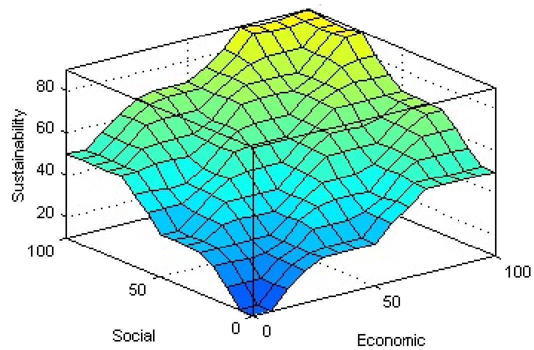


Figure 4. Rule surface

Fuzzy rule-based is an intelligent inference system to infer output values based on the input variables. Rules are generated by the system according to the combination of the linguistic labels of input and output. Since the variable input is organized by 3 sustainability dimensions with 5 linguistic labels, then the number of rules to be generated are 125 items. The rules are generated through a method proposed by Phillis et al., (2011). Therefore, the list of rules to infer industry' sustainability is listed as follow while the surface view of the input and output combination is depicted at Figure 4

1. *If (Economic is VeryLow) and (Social is VeryLow) and (Environment is VeryLow) then (Sustainability is NotSustainable) (1)*
2. *If (Economic is Low) and (Social is VeryLow) and (Environment is VeryLow) then (Sustainability is NotSustainable) (1)*

   ⋮

125. *If (Economic is VeryHigh) and (Social is VeryHigh) and (Environment is VeryHIgh) then (Sustainability is HighlySustainable) (1)*

3.3 Dashboard and model validation

The fuzzy inference system operations to infer the output needs data input, data processing and output labeling. At the process stages, at least there are 5 process that should be prepared which has been described at the previous stages. In this part, this research proposed a dashboard with has a friendly interface to facilitate user in assessing current sustainability performance of the industry.

The dashboard is depicted at the Figure 5. As aforementioned that the industry's sustainability performance is determined by economic, social and environment dimensions. To verify the model and dashboard, we demonstrate the economic, social, and environmental dimension performance as 60, 70, and 83, respectively. The sustainability dimensions values are determined arbitrarily using monte-carlo which in the next part will be validated using various condition and literatures. The simulated value in the model interpretated that the economic, social, and environmental dimensions performance are high, high, and very high, respectively. However, in the inference process of the sustainability performance the output is stated in crisp then transform into linguistic label following sustainability performance standard as defined in Khan, (2020).

The sustainability dimensions value determined the overall sustainability performance through inference model that organized by 125 fuzzy rules. The combination of consequent part from the input variables through fuzzy rule based. The defuzzification model to produce crisp output using centroid model which the crisp output is shown at Figure 6. As defined in previous stage, the fuzzy aggregation for consequent parts is using max function, therefore, the combinations of 125 rules are show at the blue lines. Applying centroid defuzzification model that was described at Equation 3, defuzzification process show crisp output with value 78.18. Based on the sustainability classification, this value is classified into sustainable as show in the dashboard.

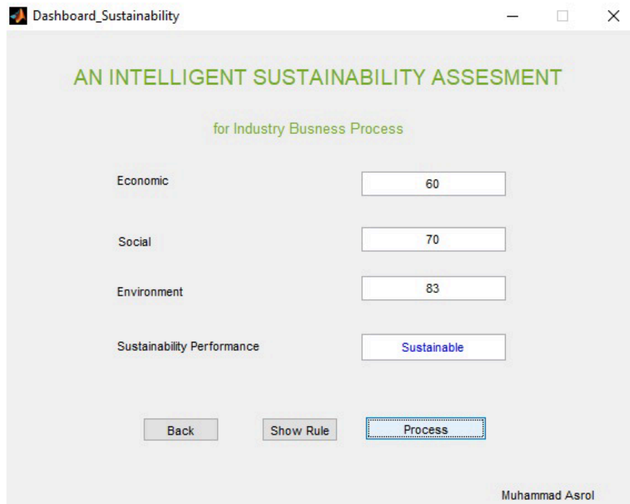


Figure 5. The front dashboard for Industry's sustainability assessment

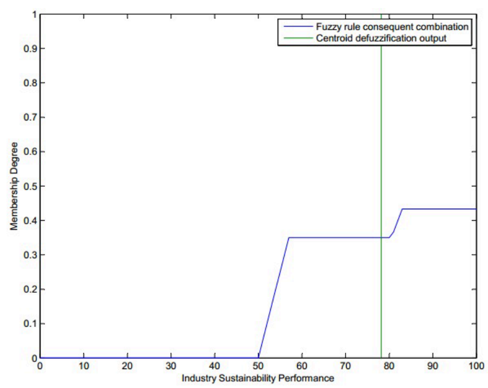


Figure 6 Defuzzification output of the model

The designed dashboard facilitates decision-maker at the industry to provide quick assessment for the current sustainability status. Moreover, the sustainability dimensions values must provide to know current sustainability performance. Further, to validate the inference model and dashboard in sustainability assessment, we provided previous research that discuss the industry's sustainability performance, as showed at Table 2.

Table 2. Model validation using various Industry's sustainability performance in previous research

No	Industry and scope	Sustainability dimensions			Author result (%)	Model result (%)	Note
		Economic (%)	Social (%)	Environment (%)			
1	Bioenergy industry (Papilo et al., 2018)	38.03	16.07	50.97	39.22 (MS)	38.05 (MS)	Valid
2	Food manufacturing (Shamraiz Ahmad et al., 2019)	42.00	16.00	76.00	42.00 (MS)	46.34 (MS)	Valid
3	Motorcycle tire (Darmawan et al., 2018)	37.24	64.78	53.02	55.95 (MS)	57.75 (MS)	Valid
4	Automotive spare part (Ghadimi Dargi and Heavey, 2017)	82.75	79.81	79.33	80.63 (MS)	88.16 (MS)	Valid
5	Coal industry (Hemdi et al., 2013)	45.00	62.00	43.00	50.00 (MS)	55.05 (MS)	Valid
6	Cacao Agroindustry (Sriwana et al., 2017)	49.19	39.85	46.62	43.07 (MS)	44.84 (MS)	Valid

4. Conclusion

This research has succeeded to design an intelligent model to infer Industry's sustainability performance. A Fuzzy Inference System model is fire well to define sustainability performance with a linguistic label that are determined by 3 dimensions, economic, social, and environment. The system is organized by 125 fuzzy rule-based to infer the sustainability performance to easily applied in the real world. A user interface for Industry's sustainability assessment has been provided for decision-makers to control the current sustainability performance. Model validation showed that the model is valid to apply in sustainability assessment in the various industrial sector.

For further research, the model and framework that has been developed in this research is possible to apply in the real world which is supported by real data acquisition and experienced expert validation.

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