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Design of Intelligent Supply Chain Decision Support Systems

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ABSTRACT
The objective of this research is to develop an intelligent decision support system (IDSS) that can aid decision-makers in enhancing the performance and sustainability of the sugarcane agroindustry's supply chain. A case study focusing on a sugarcane agroindustry supply chain was proposed. The IDSS was developed using the waterfall approach, which follows the system development life cycle (SDLC) and employed an object-oriented programming technique. The outcome of this study is a prototype of the IDSS, consisting of a database, model base, and knowledge-based management system configuration. To evaluate the sustainability of the supply chain, a fuzzy inference system and an adaptive fuzzy inference system algorithm were utilized. Through verification and validation, it was determined that the IDSS prototype has the potential to be implemented in real-world scenarios, as long as certain assumptions related to the model are taken into consideration.

Keywords: AI-Driven Supply Chains, Smart Logistics, Demand Forecasting, Inventory Optimization, Big Data Analytics, Digital Supply Chain, Cloud-Based DSS, IoT Integration, Operations Research, Autonomous Planning Systems.

1. Introduction

Sustainability is a global agenda for maintaining human life quality. This issue in the industry business process faces obstacles during the implementation phase. This delivers us to maintain the decision-making process for sustainability as the core of the strategic phase and competitive advantage in industry. Decision making plays an important role in maintaining business stability, minimizing risk, and improving sustainability [1]. Scholars have proposed a decision support system (DSS) as a supporting facility for decision-makers in the decision-making process considering real-world problems in an effective and efficient way [2]. A smart DSS was developed to cover conventional DSS limitations. A smart DSS, commonly known as intelligent DSS (IDSS), considers imprecisions and uncertain real-world problems using artificial intelligence and machine learning approaches [3]. In the framework design, an IDSS is organized specifically with a database, a model base, and a knowledge base to provide alternative decisions for solving complex problems. The new IDSS design for the decision-making process provides adaptive roles, an accurate computation model, and reliability. Looking for the ability of IDSS, inspire research to apply the IDSS to solve sustainability issues in industrial supply chains that also face complex and uncertain real- world problems.

The DSS model has been implemented in any research and industrial sector. Some of them are as follows: Reference [4–6] designed DSS for price optimization, inventory, and transportation, Reference [2,7] applied DSS for supply chain performance, while Reference [8,9] applied DSS for crop management in agroindustry. To the best of the author's knowledge, a supply chain sustainability assessment that considers imprecision and uncertainty variables and complex problems with multi-actor goals needs to be implemented in IDSS. System ability of IDSS facilitates decision makers to easily consider many issues to improve business sustainability and competitive advantages. Another issue for using IDSS in supply chain sustainability is to meet the Industry 4.0 requirement [10,11] and to reduce errors in the decision-making process for complex problems [12].

Supply chain sustainability aims to maximize business profit and minimize environmental and social impacts simultaneously [13]. In evaluating sustainability performance, indicators and dimensions have distinct units of measurement, uncertain and vague. This led us to develop an adaptive model to address real-world issues in supply chain sustainability. To take any consideration in the supply chain, this paper proposes a sugarcane agroindustry supply chain as a case study to develop a model for IDSS implementation in a sustainability supply chain.

As we know, the general approach in sustainability assessment is comprised of economic, environmental, and social dimensions, also known as triple-bottom-line. Further, as we found in the sugarcane agroindustry, previous research suggests considering resource dimensions as found in business process issues [14–16]. The sustainability assessment model applied in IDSS adopts a fuzzy approach to accommodate imprecision and uncertainty variables in the sugarcane supply chain. The fuzzy inference system (FIS) and adaptive fuzzy inference system (ANFIS) were implemented in the model. FIS and ANFIS are suitable for sustainability issues that have dynamic, multi-criteria, quantitative and qualitative values, and uncertain characteristics [17,18].

This study aims to develop an IDSS for supply chain sustainability. To validate the model, a sugarcane agroindustry in Indonesia was proposed as a case study.

1. Research framework

An IDSS development for sugarcane supply chain sustainability follows the system development life cycle (SDLC) with the waterfall model approach. This approach develops a system sequentially with a higher level of complexity [19]. The IDSS design is divided into four parts: system requirement analysis, model and system design, system implementation, and system testing and validation. The IDSS development flow is explored below.

1.1. System analysis

The system requirement analysis refer to [20] to identify acceptable and unacceptable inputs and outputs, stakeholders, resources, entities, and other supporting components. To easily follow the system requirement, a business process modelling notation (BPMN) is applied to completely analyze the system. A BPMN enables to describes the stakeholder workflow, system entity, and business process to develop the IDSS workflow [21]. In this study, the sugarcane supply chain was set as the system scope.

To accommodate the development of the IDSS, the system is analyzed through a unified modeling language (UML). UML facilitates archived, documented, illustrated, and developed software [22]. UML provides diagrams to design the system, and in this research, we illustrate the system through a use-case diagram and sequence diagram.

1.2. System design

The IDSS system configuration for a sustainable supply chain in sugarcane agroindustry is depicted in Fig. 1. As mentioned in [3], the system configuration is organized by a database management system, model-based management system, and knowledge-based management system. The database management system archives the data of field observations, expert judgment, and supporting materials to facilitate the decision-making process. Model-based management systems store mathematical computation and modelling to transform data and information into alternative solutions.

Specifically, we design the FIS and ANFIS models for sustainability assessment with considerations that deliver the results and discussion. The FIS and ANFIS models are powerful for sustainability assessment, as mentioned in [18,23]. In this research, FIS is applied for dimension sustainability and ANFIS to aggregate overall sustainability. This study contributes to the modeling of sustainability assessment using FIS with four dimensions and ANFIS aggregating overall sustainability using knowledge acquisition from the data training scheme. The indicators are designed using qualitative and quantitative approaches that have not been considered in previous works. This research also offers a complete framework, qualitative, and quantitative indicators with adaptive assessment to evaluate supply chain sustainability performance, which was previously suggested to develop immediately by Ref. [24,25].

Finally, knowledge-based organization experts and stakeholder base knowledge are related to the real-world problem for supporting the decision-making process. The user interface communicates the IDSS process and results to users with understandable language and visualization models.

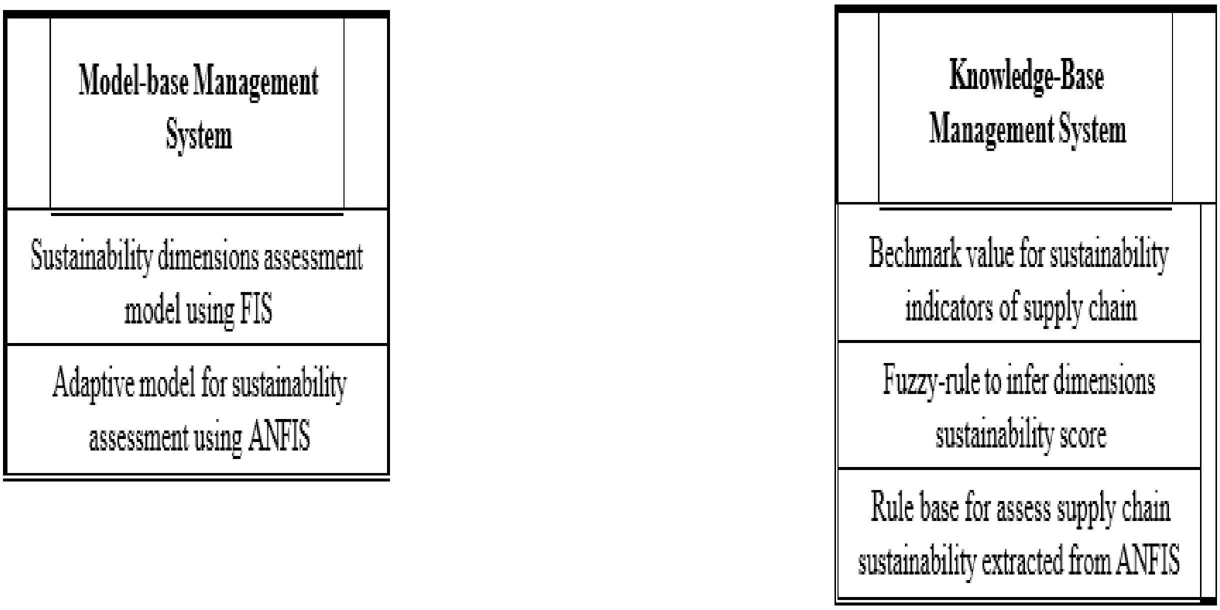

Fig. 1. IDSS configuration design

1.3. IDSS Design and Implementation

The critical stage in system design and implementation is the program-coding part. The code to be implemented follows the defined system configuration, workflow, and model based. With any consideration, this research designs the IDSS logic, code, and user interface using Java Net-Beans 8.0, using Java programming language. In addition, this application had to be supported by other apps libraries to accommodate the IDSS logic and model. Completely, apps and libraries used to design the IDSS for sustainable supply chain evaluation are listed in Table 1.

During the coding process in system development, this research applied an iterative verification process to identify possible errors in model development and system's logic implementation. The verification stages follow the black-box testing technique to check the system consistency and error of the developed software and compare it with manual operations [26].

Table 1. Application and library

Application and library	Function
Java Net-Beans IDE 8.2	Main apps for system development, coding process and user-interface design
Mat-Lab R2014a	Supporting apps for sustainability aggregation with ANFIS model
XAMPP v.3.2.4	Supporting apps for database design and application
itextpdf-5.2.1	Library for reporting and publish in Portable Document Format (PDF) format
Jcommon-1.0.14	Library for mathematical operations
Jfreechart-1.0.11	Library for visualize graph and histogram
jFuzzyLogic	Library for fuzzy operations in model development
MySQL JDBC Driver	Library for database connection

2. Result and discussion

2.1 Business Process Model Notation and Use-case diagram

A business process modelling notation (BPMN) is developed to describe the real-world business process and define the required activities and entities in IDSS design. BPMN is developed by the system analysis result that mainly focuses on the supply chain transformation in sustainability, supply chain business model, and configurations. The BPMN for sustainability assessment applied to the sugarcane supply chain is shown in Fig. 2.

IDSS development also requires a use-case diagram. The use-case for the defined case is organized into seven cases with five stakeholders. The main case of the model is defined as a supply chain sustainability assessment and potential improvement recommendations. A use-case diagram is depicted in Fig. 3.

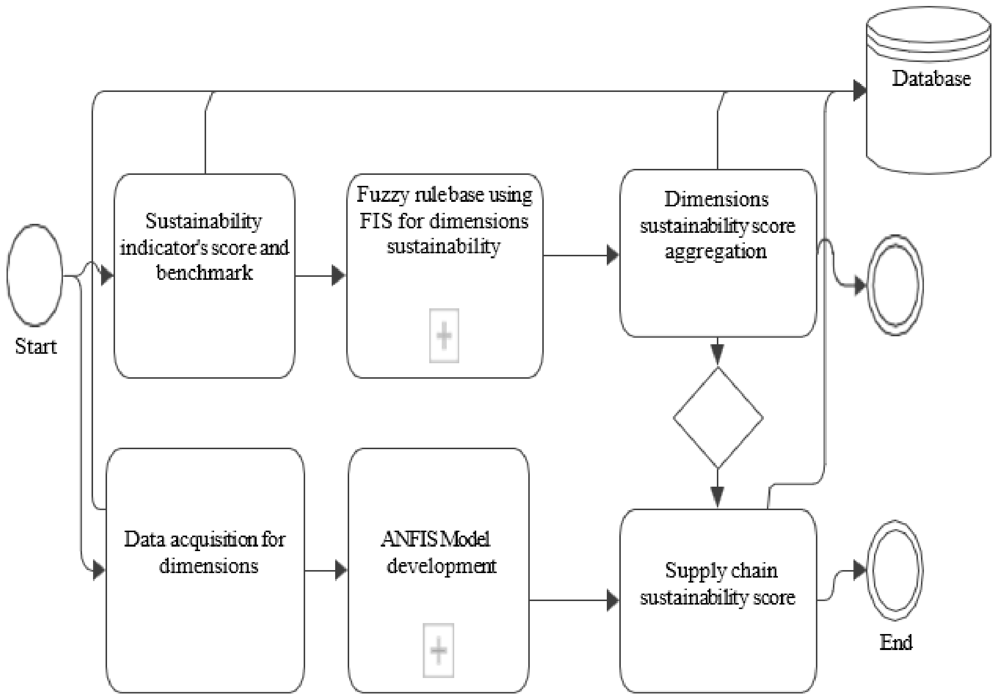

Fig. 2. BPMN for sustainability assessment

2.2. Model based

As we found in the system configuration, BPMN, and use-case diagram, the IDSS is developed using two main models: sustainability dimension assessment using FIS and aggregated supply chain sustainability using ANFIS. The model development process and its considerations are discussed in this section. In the general framework of sustainability assessment, indicators and dimensions must be defined. Indicators in sustainability assessment have to fulfill the following requirements: easy to collect the data in the real-world with numeric or categorical data type [27], indicators have been validated by expert groups and related stakeholders [28], and each sustainability dimension must be organized by at least six indicators [29].

Due to the qualification of indicators in sustainability, this research set 24 indicators and four dimensions to assess supply chain sustainability to be implemented at the IDSS. The details of the indicators and dimensions framework are shown in Fig. 4.

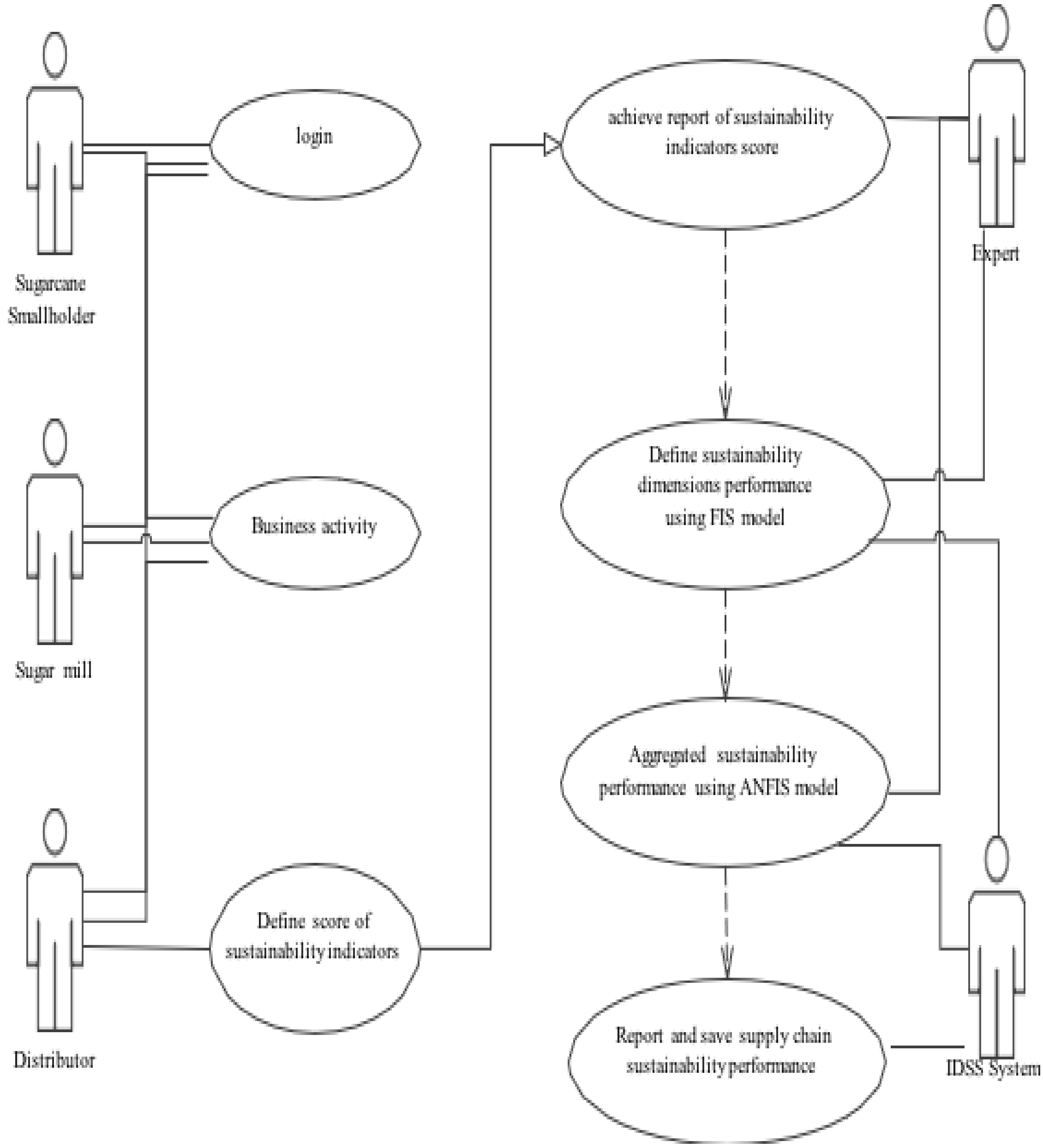

Fig. 3. Use-case diagram

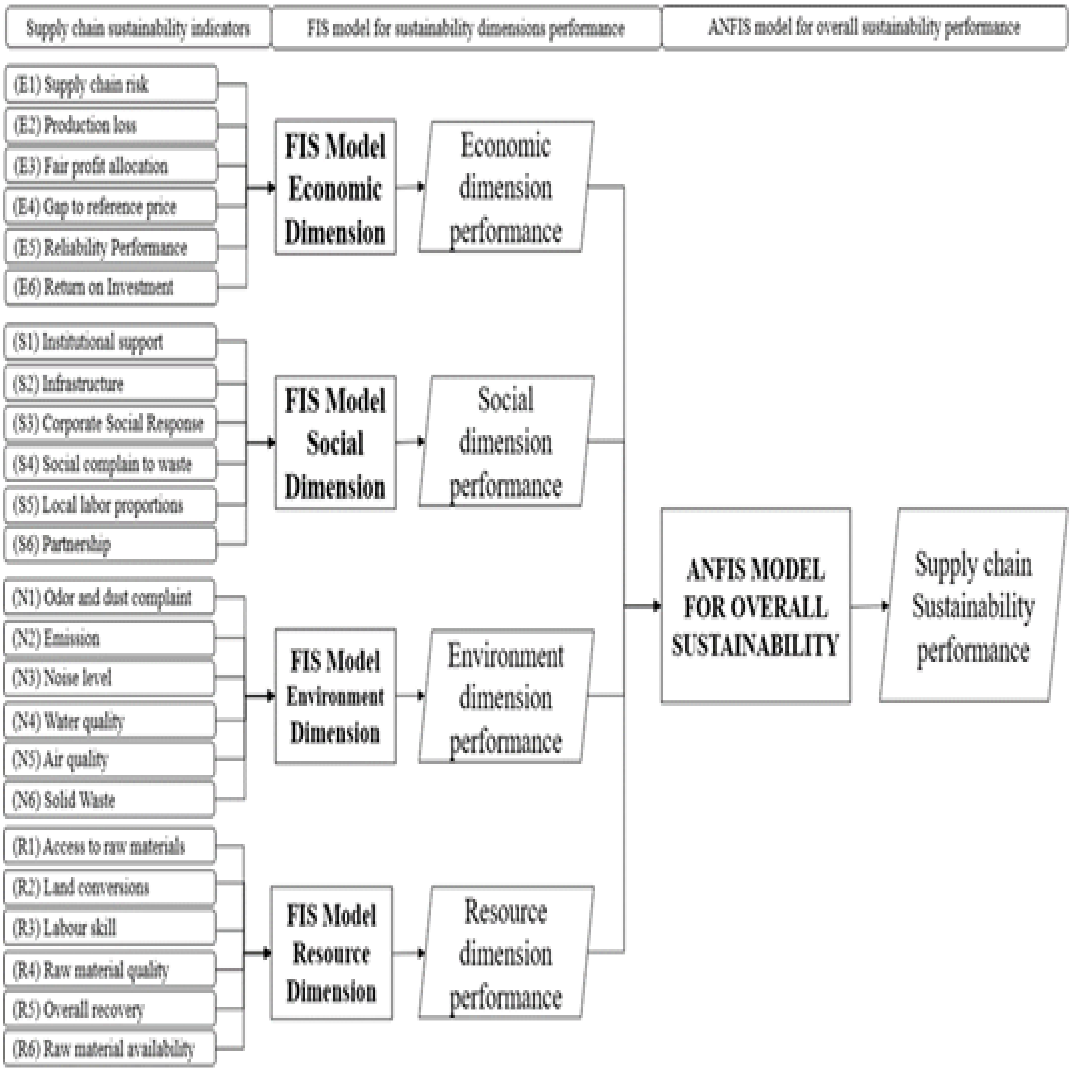

Fig. 4. Sustainability dimensions and indicators framework

As mentioned above, the input of the FIS model to infer dimensions' performance sustainability is indicators. Indicators are defined qualitatively and quantitatively to fulfill the qualifications of indicators standard in sustainability analysis. In the first stage of fuzzy modeling, the indicators were normalized. For the qualitative indicators, the normalized method is referred to [30], while quantitative ones refer to [23]. Fuzzification defines the membership degree of the normalized score in the fuzzy model. This research defines five scales of fuzzy linguistic sustainability, ranging from very low to very high. This research set the triangular fuzzy number as the fuzzification model because it has the capability to accommodate expert opinion qualitatively and quantitatively and meets the requirements of sustainability assessment [31].

The FIS model for sustainability dimension assessment requires a rule formulation in the inferring process. The number of rules is referred to Ref. [32]. Therefore, for each dimension of economic, social, environmental, and resource that has six input/indicators and five linguistic levels, 15,625 rules must be defined. In this case, the fuzzy rule formulation method is described in [33]. FIS model in dimensions performance evaluation apply Mamdani model with AND operator, MIN implication and MAX aggregation model. Referring to [34], this model has the ability to accommodate human input for complex assessment, which is complete and simple. Finally, the centroid model of aggregation was set as the defuzzification model. An illustration of the FIS model for environmental sustainability is shown in Fig. 5.

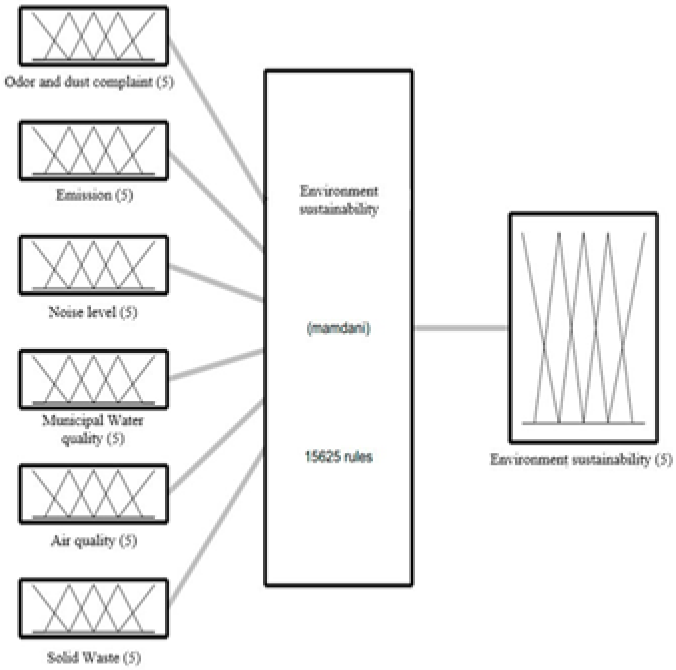

Fig. 5. FIS model for environment sustainability assessment

The ANFIS model was developed to infer overall sustainability performance. ANFIS works well in defining the membership functions and rules based on the input variables. ANFIS deals with qualitative and quantitative data, an adaptive model, and meets the requirements of sustainability analysis [18]. The ANFIS model and rules are developed through a supervised algorithm that requires training and testing schemes. The variable input for the ANFIS model is the value of the dimensions obtained by the previous FIS model.

This research prepares data training and testing through Monte Carlo with a probabilistic variable distribution. This method was also proposed in previous research [35–37]. Reference [38] suggests that the comparison of training and testing data is 3:1; therefore, this research prepares 1,000 datasets with 750 datasets for training, and the rest are testing. The complete operator for developing the ANFIS model is described in Table 2.

Finally, the model infers the sustainability performance of the sugarcane agroindustry with a numerical value. To interpret the performance, the numerical sustainability performance was classified into class labels [39]. Sustainability performance is classified into five classes: unsustainable, almost unsustainable, moderate, almost sustainable, and sustainable.

Table 2. ANFIS model for overall sustainability

No	Parameters	Function and value	Source
1	Membership function	Gaussian	[40]
2	Initiation model	Subtractive clustering	Model
3	Training model	Hybrid	[41]
4	Number of epochs	200	Model
5	Error tolerance	0	[42]

1.1. IDSS implementation and user interface

As the general framework of the supply chain sustainability evaluation, the IDSS user interface is divided into two parts: sustainability dimension performance and overall supply chain sustainability performance. For sustainability dimension performance, the fuzzy inference system (FIS) model is implemented. The FIS model for economic, social, environmental, and resource dimensions was developed using the parameters. Each dimension had 15,625 rules to infer performance. To easily access the FIS model for evaluation, a user interface was designed. For illustration, a user interface to evaluate supply chain sustainability in the recourse dimension is depicted in Fig. 6.

The system demonstrates six indicators involving five quantitative and the rest qualitative for resource dimensions. The user is allowed to see the target value and benchmark of the specific indicators. The input space for the user is provided at the data column on the far left. The performance of each indicator is provided at the bottom left after the defuzzification process, with the highest value for each indicator being 1. Finally, using the developed FIS model, the resource dimension performance is provided at the bottom right of the interface. In this case, the resource dimension performance is 50.38, which is classified as almost unsustainable.

Furthermore, the supply chain sustainability assessment requires aggregation to provide information on overall supply chain sustainability performance. This research applies ANFIS with subtractive clustering model initiation to produce rules for aggregating overall supply chain sustainability performance. For comparison, the subtractive clustering model initiation required 2.50 minutes for model validation, while the grid partition model required 24 h. The subtractive clustering model produces 26 rules with error under 1.3×10^{-5}. The subtractive clustering model works efficiently for this case, which is also in line with Ref. [43], which proves that subtractive clustering is better than grid partition initiations.

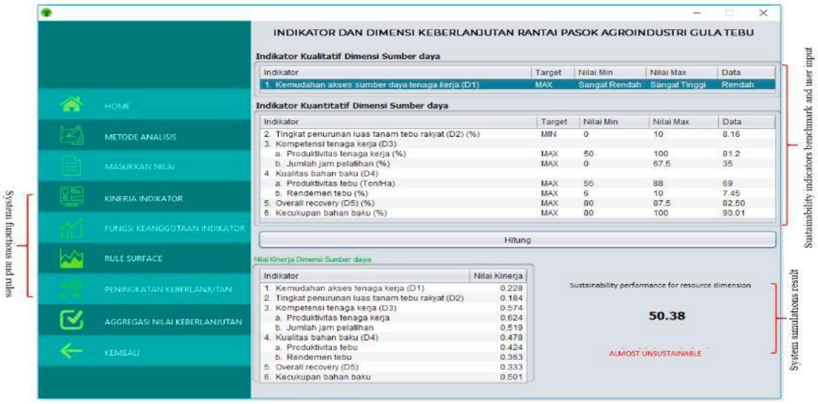

Fig. 6. User-interface for resource dimensions performance evaluation

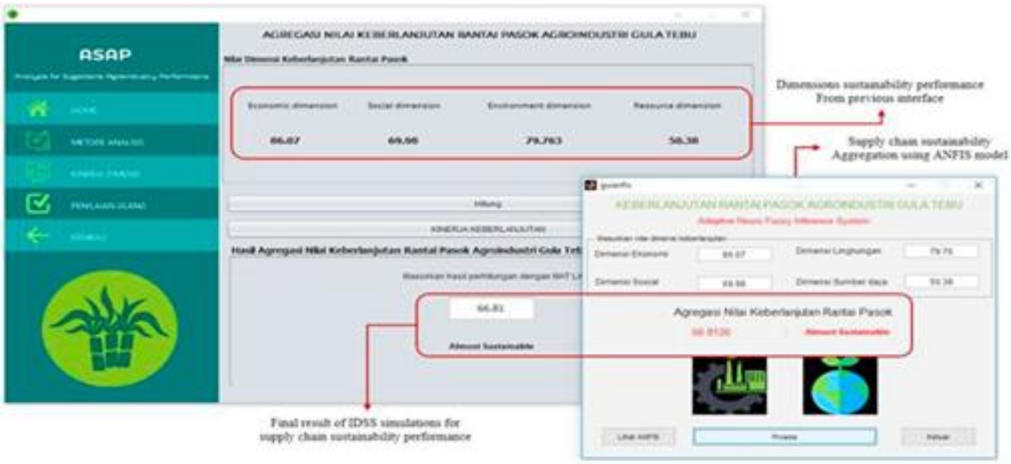

Fig. 7. User-interface for supply chain sustainability performance aggregation using ANFIS.

As previously mentioned, the ANFIS model aggregation is implemented in the IDSS design to determine the overall supply chain sustainability performance. The ANFIS model for sustainability performance evaluation required dimensions of economic, social, environmental, and resource dimensions, which are provided by previous stages. The dimensional performance is aggregated using the ANFIS algorithm with defined functions and parameters, as defined in Table 2. The implementation of the ANFIS model for sustainability assessment was provided at the IDSS user interface. The user can access the assessment system to determine the current supply chain sustainability performance, as depicted in Fig. 7.

Users can also input the performance dimensions of the supply chain sustainability. The IDSS with the ANFIS model aggregates the overall supply chain sustainability performance. The IDSS demonstrates that the current overall supply chain sustainability performance is 66.81, which is classified as almost sustainable.

1.2. IDSS testing and validation.

Testing and evaluation of the IDSS is the final stage to ensure that the system is ready to use. In this stage, we applied black box testing to demonstrate the reliability of the system. In the IDSS testing scheme, a comparison is provided to show the error rate of the system to the manual process. The error rate was calculated using the RMSE.

Table 3. ANFIS model for overall sustainability

Test no	Function	System	Manual	Gap
1	Indicator’s normalization	0.492	0.491	0.001
2	Indicator’s normalization	0.267	0.267	0.000
3	Indicator’s normalization	0.802	0.802	0.000
4	Indicator’s normalization	0.920	0.920	0.000
5	Indicator’s normalization	0.598	0.554	0.044
6	Inference model	0.588	0.588	0.000
7	Inference model	0.495	0.495	0.000
8	Inference model	0.757	0.757	0.000
9	Inference model	0.889	0.886	0.003
10	Inference model	0.574	0.574	0.000

The IDSS testing and validation are described in Table 3. The system error showed a very low RMSE value. The IDSS enables the transformation of the input into output by considering the assumptions. The testing and validation process provides that the system is ready to be implemented by the decision-maker in the agro-industry.

Conclusion

This research has successfully designed and used IDSS for supply chain sustainability assessment with sugarcane agroindustry as a case study. The system is organized by two main models: FIS for dimension sustainability assessment and the ANFIS model with subtractive clustering for the overall supply chain sustainability aggregation. A system analysis and design with BPMN and a use-case diagram were provided to implement the model in the interactive user interface. The IDSS has successfully demonstrated a supply chain sustainability assessment for the dimension assessment and overall assessment. The system infers that the current supply chain sustainability for the sugarcane agroindustry is almost sustainable. This research offers a complete framework for sustainability assessment, considering qualitative and quantitative indicators, evaluating sustainability dimensions, and aggregating sustainability performance using adaptive modelling and approach.

For further research, it is possible to expand the research model, sustainability dimensions, and indicators to be applied in other agro-industrial sectors to evaluate and maintain supply chain sustainability.

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