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Implementing Fuzzy Logic to Forecast Electricity Usage Costs

Ade Riyanti[1*]
[1*]Computer Engineering Technology Study Program, College of Vocational School, IPB University
aderiyanti@apps.ipb.ac.id

Arda Dwiyana[2], Danar Restu Firdaus[3], Danke Hidayat[4], Fajri Haykal Rahman[5], Muhammad Rafi Ari Ghani[6], Agung Prayudha Hidayat[7], Dwi Yulinar Chairunisa[8]
[2345678]Computer Engineering Technology Study Program, College of Vocational School, IPB University
[2]ardadwiyana@apps.ipb.ac.id, [3]danarrestu@apps.ipb.ac.id, [4]dankehidayat@apps.ipb.ac.id, [5]fajrihaykal@apps.ipb.ac.id, [6]rafighani@apps.ipb.ac.id, [7]agungprayudha@apps.ipb.ac.id, [8]dwi.yulinar8@gmail.com

Abstract

Electricity has a very vital role in human life, being a form of energy that is inseparable from various aspects of daily activities. The greater the use of electricity will have an impact on increasing the cost of electricity use. By applying fuzzy logic methods, research focuses on understanding the efficiency of electrical power use, identifying key factors that affect efficiency at the household level. This study aims to apply the Mamdani method in fuzzy logic to predict the cost of electricity consumption and measure the level of accuracy of the implementation of fuzzy logic. The variables used as the basis of the study involved house size, electronic equipment, electrical power, economic income, and electricity usage cost. The implementation of this research will use Matlab software because it provides various tools for the Mamdani method. The results of the implementation of fuzzy logic with the Mamdani method for the example case analyzed in obtaining electricity usage cost that needs to be paid is Rp. 455,500. Thus, these results indicate that the Mamdani method in fuzzy logic is effectively used to predict electricity usage cost in Leuwimekar Village, Bogor City.

Keywords: Electricity, Fuzzy Logic, Matlab, Mamdani Method.

INTRODUCTION

Electricity has a very vital role in human life, being a form of energy that is inseparable from various aspects of daily activities (Olanda and Susilo 2021). His presence has a significant impact on the implementation of various activities, ranging from cooking, the learning process, work, to entertainment and others. All this is possible thanks to electricity, a resource that is becoming irreplaceable as technology advances rapidly.

Advances in technology and science today accelerate the birth of new innovations that essentially use electricity as their main energy source. Thus, the need for electrical energy has also increased significantly in various dimensions of life (Suprapto and Simanjuntak 2020). This illustrates that electricity has a crucial role in supporting the growth and evolution of modern society. Therefore, efforts to meet electricity needs are becoming increasingly important in order to maintain the balance and continuity of various human activities that are increasingly complex and dependent on technology (Rahmah and Irawan 2019).

In line with that, the high development of technology has also contributed to the creation of modern equipment which is now the main need in everyday life (Yulianti and Wijaya 2014). These appliances ranging from kitchen devices to sophisticated electronic devices, all require electrical energy to operate effectively. Thus, the existence of electricity is not only a necessity, but also the main key in spurring progress and comfort of life.

Humans directly feel dependence on electrical energy when there is a disturbance that results in a power outage. As a result, all electronic equipment that depends on electricity supply stops in carrying out its duties, both in the industrial sector and in household appliances. In this situation, not only human daily activities are stopped, but also various processes and operations at the industrial and household levels are seriously affected by the shutdown of electricity supply. In the industrial sector, production machinery stops operating, resulting in decreased productivity and potential economic losses. At the household level, electronic appliances such as refrigerators, televisions and other devices become unusable, creating inconvenience for residents of the house (Sasmito and Nabunome 2018).

The increasing public demand for electricity supply will result in the need for an increase in the amount of electricity production. This condition creates a number of challenges in maintaining the availability of adequate electricity supply to meet consumer needs (Suprapto and Simanjuntak 2020). Adding power plants is one way to increase the capacity to provide electrical energy to meet the electrical energy needs of society and industry. Apart from that, there is also outreach about the importance of saving electrical energy (Asy, Budiman, and Munadi 2013). These efforts are becoming essential to keep pace with and meet the evolving needs of the community.

The need for electricity will continue to increase along with population growth and development, investment and technological development, including the development of education at all levels (Rajagukguk, Pakiding, and Rumbayan 2015). The demand for electrical energy generally increases in proportion to the level of economic activity and the number of inhabitants in the region (Santoso and Salim 2019). Although electricity generation efforts are relatively difficult because they are hampered by fluctuating economic changes in Indonesia and the world, electricity consumption will definitely increase along with the increasing population of Indonesia (Wahid, Junaidi, and Arsyad 2014).

The use of electricity is very important for all levels of society, even not only as the main element in the production process, but also to support daily activities (Biasrori, Arimbawa, and Wedashwara W. 2019). Excessive use of electrical energy will adversely affect oneself and the environment. Many factors affect excessive electricity use such as water usage, electricity switches that continue to flow and unnecessary use of electrical tools. Saving electricity costs will have an impact on electricity costs and bills. One factor that significantly affects the cost of electricity is the area of the house, electrical power, and electronic equipment (Harahap et al. 2019). Efforts to save electrical energy used by making a technology that can measure automatically and efficiently. The technology used is to monitor electricity consumption used in household electronic devices so that there is no waste of electricity consumption (Isnen 2022).

The use of intelligent systems, one part of computer science, can help calculate the operational costs of electricity used in everyday life. The use of this intelligent system uses an algorithm, namely Fuzzy Logic Control (FLC) to get a more optimal output value. By doing calculations using fuzzy logic with input of house size, electrical power, electronic equipment, and economic income will produce output in the form of electricity usage costs (Hunaini, Adisyahrudin, and Setiawidayat 2022). The advantages of using fuzzy logic include that its mathematical concepts and simple reasoning make this fuzzy logic easy to understand and the results of the reasoning provide a more rigorous output (Effendi 2009).

The state electricity company provides electricity supply for which each user must pay a fee based on the amount of electricity used. The calculation of power usage is done by multiplying the time by one kilowatt hour, which is recorded on kilowatt hour meters (KWH meters). The monitoring and decision-making system is a form of supervision and decision-making related to the use of electrical power in the household, which can be controlled directly by the owner as they wish (Dawe 2021). Therefore, the concept of fuzzy logic can be applied in everyday situations such as monitoring electrical energy usage, weather prediction, credit scoring for home purchases, and other things (Yulianti and Wijaya 2014).

Fuzzy logic is a type of logic derived from fuzzy set theory. Fuzzy set theory was introduced by Zadeh in 1965 as a way to overcome uncertainties that arise due to inaccuracies and vagueness (Zadeh 1965). In use, fuzzy logic can be applied to data that is not completely valid or data of a linguistic nature defined by membership functions. Unlike the traditional calculation approach which only takes into account the value of the interval between 0 and 1 (Rosalina, Farida, and Hamid 2016). Fuzzy logic is a type of logic that uses grouped, quantified statements rather than one-time true or false statements (Suhaila et al. 2024) and a form of logic that can be used to analyze problems involving uncertainty (Afifah Rodhiyatun Nisa et al. 2024).

Ebrahim Mamdani introduced a method known as the Mamdani method or also referred to as the Max-Min Method in 1975. Mamdani's fuzzy logic is used effectively in predicting electrical energy consumption due to its simple advantages. The use of Mamdani's fuzzy logic in this prediction is based on a simple structure, using Min-Max or Max product operations with a predefined set of rules, namely IF.... AND.... THEN (Ningsih, Pambudi, and Abadi 2017). The Mamdani method involves four steps to produce its output. One software that can be used to implement fuzzy logic systems is Matlab (Matrix Laboratory). Matlab provides a variety of tools to apply the Mamdani method (Siskandar et al. 2023).

Several studies on the prediction of electricity use have been carried out by several researchers, such as Haryanto & Nasari (2015) and Suprapto & Simanjuntak (2020). In addition, studies using fuzzy logic with the Mamdani method have been conducted by Muthohar & Rahayu (2016), Wardani, Nasution, & Amijaya (2017), and Maibang & Husein (2019). Based on research by Haryanto & Nasari's (2015) involving the fuzzy method of Mamdani and Sugeno with the help of Matlab software, it was found that the Mamdani method has a better level of accuracy compared to the Sugeno method. Conversely, the results of Suprapto & Simanjuntak's (2020) research with three input variables, namely power, total kWh, and time, concluded that fuzzy Mamdani can be effectively used to forecast electricity consumption.

Based on the discussion above, researchers conducted research by developing research conducted by Haryanto & Nasari (2015) and Suprapto & Simanjuntak (2020). This study adds economic income variables as input variables, because economic income has an indirect influence on the cost of electricity consumption. In addition, the variable cost of electricity consumption is used as the output variable. Therefore, there are four input variables used, namely house size, electrical power, electronic equipment, and economic income. Electrical power and electronic equipment are considered as direct influential factors, while home area and economic income are considered as factors that indirectly affect the cost of electricity consumption. Furthermore, this study implements Mamdani's fuzzy logic to predict the cost of electricity usage in Leuwimekar Village, Bogor City. Thus, this study aims to implement the Mamdani Method in fuzzy logic to predict the cost of electricity use and obtain the level of accuracy of the results from the application of fuzzy logic.

METHODS

Time and Location

This research was carried out from January to April. The location of this research is in Leuwimekar Village, Bogor City.

Data Collection Technique

The procedures used to evaluate or collect data are called data collection techniques. Data collection approaches work well independently of data analysis techniques and can also play an important role in these steps. There are various approaches to data collection, including descriptive, correlational, experimental, qualitative, quantitative and observational methods (Nadialista Kurniawan 2021).

Quantitative research methods were chosen as the data collection method in this research. This method usually involves identifying the root causes of relationships by organizing elements systematically. This quantitative method is a type of research that has systematic, planned and clearly

defined specifications starting from initial conception to research design (Hermawan et al. 2022) . The aim of this research is to determine the extent of influence of a variable on other variables studied. Quantitative research methods involve several steps:

1. Study Literature

   The process of gathering information for literature study is to understand and collect theories from various books related to research. The four steps in this approach are scheduling, reading, and summarizing research materials (Adlini et al. 2022). To conduct research on our project, Implementing Fuzzy Logic to Forecast Electricity Usage Costs, we first collected information from journals. In addition, we are exploring data processing methods using fuzzy logic, which will subsequently continue to be used to calculate data for our research.

2. Interview

   Interviews are a data collection technique that involves direct interaction between researchers and research participants (Ardiansyah, Risnita, and Jailani 2023). In our research, we also collected data by conducting interviews with one of the residents of Leuwimekar village, Bogor city.

Data Analysis Techniques

In June 1965, Professor Lotfi A. Zadeh of the University of California introduced the concept of fuzzy logic for the first time (Astry, Surjasa, and Sugiarto 2017). The main principle of fuzzy logic is fuzzy set theory. In this theory, the role of membership degrees becomes a key factor in determining the existence of elements in a set. The main feature of reasoning with fuzzy logic is the value of membership or degree of membership (Andani 2013). This theory states that the degree of membership of an element in a set is not limited to 0 and 1 only (as a non-member or member of the set), and the value tested is not limited only to 0 and 1. It is as if there is a "gray" area that has logic between the range 0 and 1 (Haryanto and Nasari 2015).

In the field of artificial intelligence, fuzzy logic is one of several algorithms studied. The application of fuzzy logic involves various fields, such as the medical field (to detect disease), the field of economics, and other fields. In general, fuzzy logic is applied in dealing with problems involving uncertainty. There are several reasoning techniques used in the development of fuzzy systems, such as the Tsukamoto, Mamdani, and Sugeno methods (Jayanti and Hartati 2012). In this study, researchers used the Mamdani method to solve the problem of determining the cost of electricity consumption. Because the Mamdani method is not too complicated and more relevant to be applied to these problems. The Mamdani method, commonly known as the Max-Min Method, was introduced by Ebrahim Mamdani in 1975 (Vinsensia and Utami 2018). Here are some of the steps required to obtain the output: (Arifin, Muslim, and Sugiman 2016)

1. Formation of Fuzzy Sets

   Define an appropriate fuzzification function for each input variable. At this stage, each input or output variable will be divided into one or more fuzzy sets (Friska Narulita and Ahmad 2024).

2. Application Function Implications

   Stringing together basic rules, which include rules in the form of fuzzy implications stating the relationship between input variables and output variables. The number of rules is determined by the number of linguistic values present for each input variable. The Mamdani method employs the Min implication function (Priyo 2017).

3. Composition of Rules

   The fuzzy Mamdani method used in inference is the Max method (Muflihunna and Mashuri 2022). Inference is obtained through the concatenation and correlation between rules. In this method, the fuzzy set solution is obtained by taking the maximum value of each rule, then that value is used to modify the fuzzy region and applied to the output by using the OR (join) operator. After testing each proportion, the result will include a fuzzy set reflecting the contribution of each proportion (Priyo 2017).

4. Defuzzification

   Defuzzification is a step in fuzzy methods where fuzzy output resulting from fuzzy inference is converted into definite values or concrete decisions (Zain Muzadid Zamzani, M. Ryan Nurdiansyah N.A, and Baktiar Yudha Yana 2023). The fuzzy Mamdani method used in defuzzification is the centroid method (Ilham and Fajri 2020). This method uses the moment value and area of the output variable based on the choice of fuzzy operator used (Santosa, Hidayat, and Siskandar 2021).

Research Phase

This research involves several steps such as, literature study, problem formulation, problem solving, and conclusions.

1. Literature Study

   Researchers use literature studies to obtain data as a reference. At this stage, the step taken is to collect various relevant library sources, such as books, journals, theses, and other sources related to research. The data obtained cover topics such as fuzzy logic, fuzzy set concepts, Mamdani method, Matlab, and electrical power. After that, an in-depth understanding of the contents of the library sources that have been collected is carried out, so that it can be used as a basis for analyzing research problems.
2. Problem Formulation

   Problem formulation is needed to overcome the limitations of the problem, so as to get a clear research focus and facilitate the determination of steps to overcome the problem.
3. Problem Solving

   By referring to the existing problem, steps are taken to solve the problem:

   a. Data Collection

      Data collection was conducted by interviewing respondents (people of Leuwimekar Village, Bogor City) who had random meters.

   b. Defining Variables

      The variables used in this study are, variables of house size, electronic equipment, economic income, and electricity usage costs.

   c. Formation of Fuzzy Sets

      In this step, the fuzzy process is carried out for each fuzzy variable by forming several fuzzy sets for each input and output variable.

   d. The Establishment of Fuzzy Rules

      At this stage, the preparation of rules in the form of fuzzy implications is carried out to describe the relationship between input variables and output variables.

   e. Implementation Design

      In this step, the implementation design is carried out on the Matlab software.

   f. System Testing

      In this step, system testing is carried out by analyzing data on the system that has been built with manual calculations. Data analysis using Mamdani's fuzzy logic.
4. Conclusion

   The final stage in a study is to draw conclusions. In this section, conclusions are drawn resulting from the analysis of the results of problem solving. Thus, this conclusion includes information about the problem that has been studied.

RESULTS AND DISCUSSION

Data

In conducting this research, data related to the factors causing the high and low cost of electricity consumption are needed which include the area of the house, electronic equipment, electrical power, and economic income.

Defining Variables

In this study there are 5 variables consisting of 4 input variables and 1 output variable, as in Table 1.

Table 1. Defining Variables

Function	Variable Name	Unit
Input	House Size	m^2
	Electrical Power	VA
	Electronic Equipment	Unit
	Economic Income	Rupiah
Output	Electricity Usage Costs	Rupiah

Formation of Fuzzy Sets

The formation of fuzzy sets is also called the fuzzification process which is the process of converting decisively valued input data into inputs in the form of degrees of fuzzy set membership. The formation of fuzzy sets in the prediction of electricity consumption costs can be seen as in Table 2.

Table 2. Formation of Fuzzy Sets

Variable Name	Fuzzy Sets	Domain
House Size	STANDARD	[0 55]
	MEDIUM	[40 120]
	BIG	[105 250]
Electrical Power	LOW	[0 900]
	MEDIUM	[450 1350]
	HIGH	[900 2200]
Electronic Equipment	LITTLE	[1 7]
	NORMAL	[5 13]
	LOTS	[11 18]
Economic Income	LOW	[0 2,5]
	MEDIUM	[2 6,5]
	HIGH	[6 10]
Electricity Usage Costs	LOW	[0 300]
	MEDIUM	[200 500]
	HIGH	[400 1200]

The Establishment of Fuzzy Rules

Table 3. The Establishment of Fuzzy Rules

No	House Size	Electrical Power	Electronic Equipment	Economic Income	Electricity Usage Costs
1	STANDARD	LOW	LITTLE	MEDIUM	LOW
2	STANDARD	LOW	LITTLE	HIGH	LOW
3	STANDARD	HIGH	NORMAL	LOW	MEDIUM
4	STANDARD	MEDIUM	LOTS	LOW	HIGH
5	MEDIUM	LOW	LITTLE	LOW	LOW
6	MEDIUM	LOW	LITTLE	MEDIUM	LOW
7	MEDIUM	MEDIUM	NORMAL	MEDIUM	MEDIUM
8	MEDIUM	HIGH	NORMAL	HIGH	MEDIUM
9	BIG	LOW	LITTLE	LOW	LOW
10	BIG	LOW	NORMAL	MEDIUM	MEDIUM
11	BIG	MEDIUM	NORMAL	LOW	MEDIUM
12	BIG	HIGH	LOTS	HIGH	HIGH

Implementation Design

The implementation design is carried out using Matlab R2015a software as a platform to obtain data on the predicted cost of electricity consumption.

1. The design of the fuzzy inference system diagram can be seen in Figure 1.

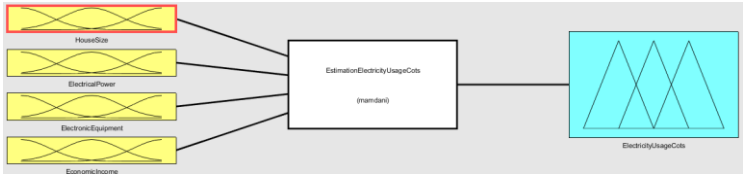

Figure 1. The Design of the Fuzzy Inference System Diagram

2. The design of the house size input can be seen in Figure 2.

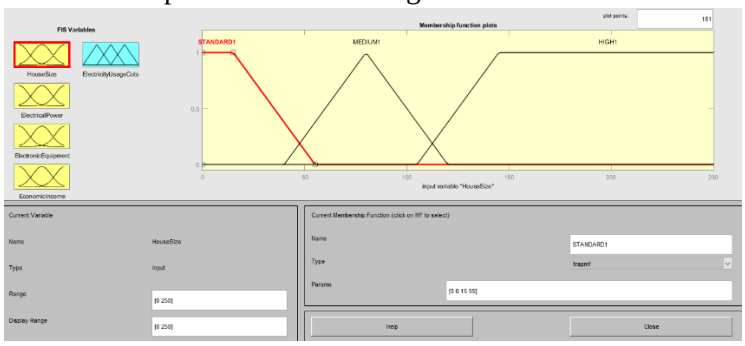

Figure 2. The Design of the House Size Input

3. The design of the electrical power input can be seen in Figure 3.

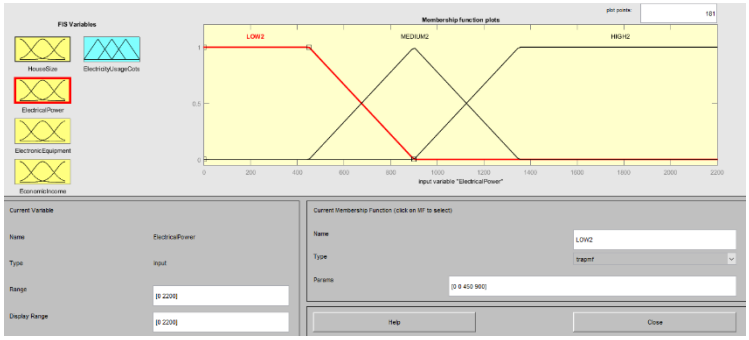

Figure 3. The Design of the Electrical Power Input

4. The design of the electronic equipment input can be seen in Figure 4.

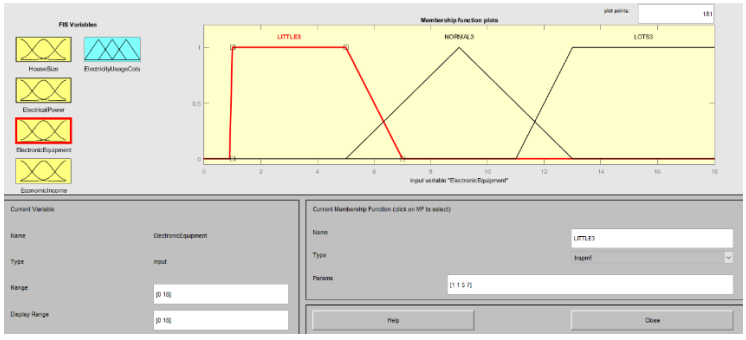

Figure 4. The Design of the Electronic Equipment Input

5. The design of the economic income input can be seen in Figure 5.

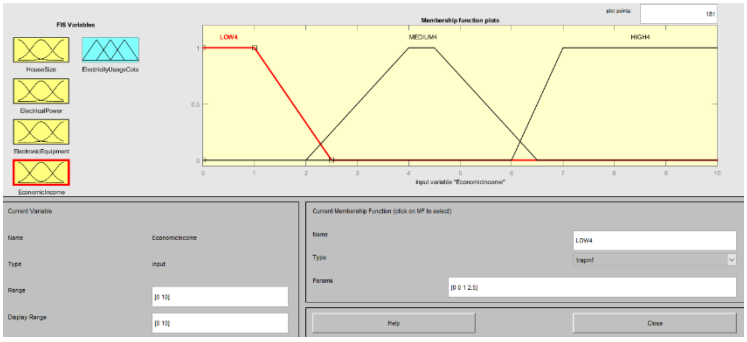

Figure 5. The Design of Economic Income Input

6. The design of the electricity usage cost output can be seen in Figure 6.

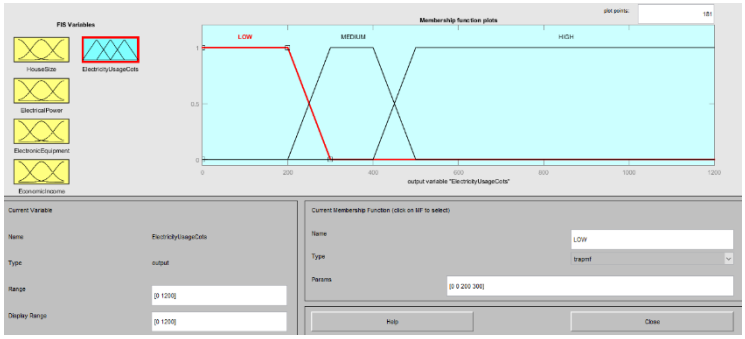

Figure 6. The Design of the Electricity Usage Cost Output

7. The design of the fuzzy rules can be seen in Figure 7.

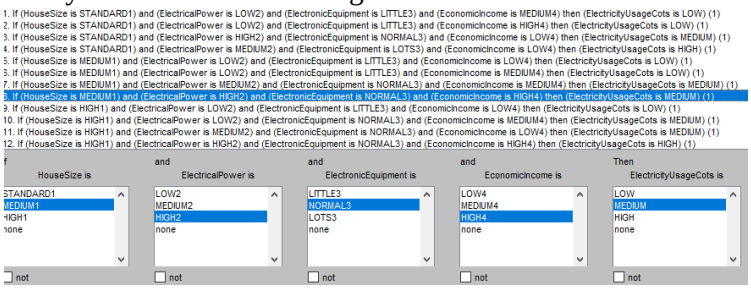

Figure 7. The Design of the Fuzzy Rules

System Testing

System testing is carried out after the system is formed to determine the prediction of electricity usage costs based on home area, electrical power, electronic equipment, and economic income. In this study, researchers carried out manual calculations of the Fuzzy Inference System of the Mamdani Method. In the example case taken, Respondent 1 has a house size of 90 m2, the electrical power used is 2200 VA, the number of electronic equipment used is 10 units, and the monthly economic income is Rp25,000,000. How much is the predicted cost of electricity usage that needs to be paid?

1. Formation of Fuzzy Sets
   a. The membership function of the house size of 90 m^2 can be seen in Figure 8.

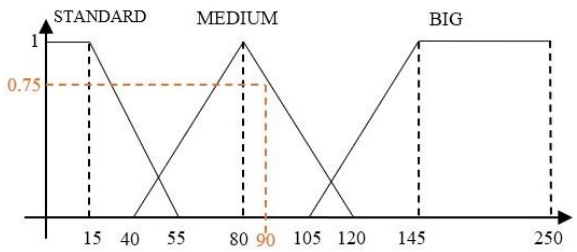

Figure 8. The Membership Function of The House Size of 90 m^2

Input Membership Set:

$$f(x,a,b,c,d) = \begin{cases} 0 & x \leq 40 \\ \dfrac{40-x}{80-40} & 40 \leq x \leq 80 \\ \dfrac{120-x}{120-80} & 80 \leq x \leq 120 \\ 0 & x \geq 120 \end{cases}$$

Membership Functions:

$$\mu_{ha\ MEDIUM}(63) = \frac{c-x}{c-b} = \frac{120-90}{120-80} = 0{,}75$$

b. The membership function of electrical power of 2200 VA can be seen in Figure 9.

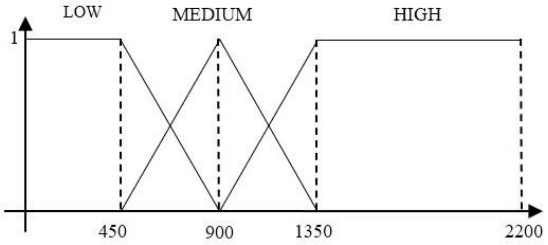

Figure 9. The Membership Function of Electrical Power of 2200 VA

Input Membership Set:

$$f(x,a,b,c,d) = \begin{cases} 0 & x \leq 900 \\ \dfrac{x-900}{1350-900} & 900 \leq x \leq 1350 \\ 1 & 1350 \leq x \leq 2200 \end{cases}$$

Membership Functions:

$$\mu_{ep\ HIGH}(2200) = 1$$

c. The membership function of 10 units of electronic equipment can be seen in Figure 10.

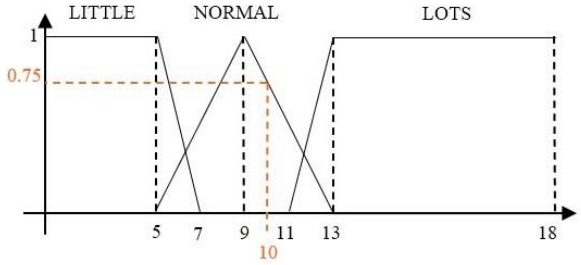

Figure 10. The Membership Function of 10 Units of Electronic Equipment

Input Membership Set:

$$f(x,a,b,c,d) = \begin{cases} 0 & x \leq 5 \\ \dfrac{x-5}{9-5} & 5 \leq x \leq 9 \\ \dfrac{13-x}{13-9} & 9 \leq x \leq 13 \\ 0 & x \geq 13 \end{cases}$$

Membership Functions:

$$\mu_{ee\ NORMAL}(10) = \frac{c-x}{c-b} = \frac{13-10}{13-9} = 0{,}75$$

d. The membership function of monthly economic income of Rp25,000,000 can be seen in Figure 11.

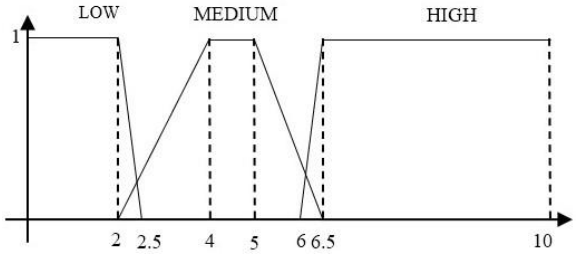

Figure 11. The Membership Function of Monthly Economic Income of Rp25,000,000

Input Membership Set:

$$f(x,a,b,c,d) = \begin{cases} 0 & x \leq 6 \\ \dfrac{x-6}{7-6} & 6 \leq x \leq 7 \\ 1 & 7 \leq x \leq 10 \end{cases}$$

Membership Functions:

$\mu_{ei\ HIGH}(25) = 1$

2. Application Function Implications

IF house size MEDIUM, electrical power HIGH, electronic equipment NORMAL, economic income HIGH, THEN electricity usage costs MEDIUM.

$$\mu_{R1} = \min(\mu_{\text{ha MEDIUM}}[90],\ \mu_{\text{ep HIGH}}[2200], \mu_{\text{ee NORMAL}}[10], \mu_{\text{ei HIGH}}[25])$$
$$= \min(0{,}75, 1, 0{,}75, 1)$$
$$= 0{,}75$$

3. Composition of Rules

The result area of the rule composition can be seen in Figure 12.

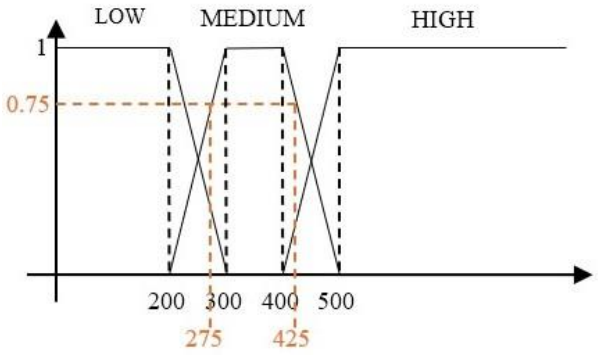

Figure 12. The Result Area of The Rule Composition

Next,define the intersection point of the rule when $\mu_{euc\ MEDIUM} = 0{,}75$ as follows:

a. Intersection point 1

$$\alpha_1 = \frac{Z_1 - 200}{300 - 200}$$
$$0.75 = \frac{Z_1 - 200}{100}$$
$$75 = Z_1 - 200$$
$$Z_1 = 275$$

b. Intersection point 2

$$\alpha_2 = \frac{500 - Z_2}{500 - 400}$$
$$0.75 = \frac{500 - Z_2}{100}$$
$$75 = 500 - Z_2$$
$$Z_2 = 425$$

Thus, a fuzzy solution area is obtained as shown with the following membership function:

$$f_{(x,a,b,c,d)} = \begin{cases} 0 & x < 200 \\ \dfrac{x - 200}{300 - 200} & 200 \le x \le 275 \rightarrow 0{,}01x - 1 \\ 0{,}75 & 275 \le x \le 425 \rightarrow 0{,}75 \rightarrow \int_a^b (x)X.dx \\ \dfrac{500 - x}{500 - 400} & 425 \le x \le 500 \rightarrow 5 - 0{,}01x \\ 0 & x > 500 \end{cases}$$

4. Defuzzification

The calculation of defuzzification when the house size is 90 m2, electrical power is 2200 VA, electronic equipment is 10 pieces, and economic income is IDR 25,000,000 is as follows:

$$M_1 = \int_{200}^{275} (0.01x - 2)x\, dx$$
$$= 7031{,}25$$
$$M_2 = \int_{275}^{425} (0.75)x\, dx$$
$$= 39375$$
$$M_3 = \int_{425}^{500} (5 - 0{,}01)x\, dx$$
$$= 12656{,}25$$
$$LD_1 = \frac{(275 - 200)0.75}{2}$$
$$= 28{,}125$$
$$LD_2 = (425 - 275)0{,}75$$
$$= 112{,}5$$
$$LD_3 = \frac{(500 - 425)0.75}{2}$$
$$= 28{,}125$$

Thus, the center point of the fuzzy area is obtained as follows:

$$\mathrm{Z} = \frac{\int_a^b f_{(x)}Xdx}{\int_a^b f_{(x)}dx}$$
$$= \frac{M_1 + M_2 + M_3}{LD_1 + LD_2 + LD_3}$$
$$= \frac{7031{,}25 + 39375 + 12656{,}25}{28{,}125 + 112{,}5 + 28{,}125}$$
$$= 350$$

The results of the defuzzification calculation when the area of the house is 90 m2, electrical power is 2200 VA, electronic equipment is 10 units, and economic income per month is Rp. 25,000,000 obtained the cost of electricity consumption that needs to be paid is Rp350.000.

CONCLUSION

Based on the results of research on the implementation of fuzzy logic with the Mamdani method in predicting the cost of electricity consumption in Leuwimekar Village, Bogor City, it can be concluded that the implementation of fuzzy logic with the Mamdani method in predicting the cost of electricity consumption with the help of Matlab software is carried out with 4 stages, namely the formation of fuzzy sets by dividing each variable into 3 fuzzy sets, the application of implication functions using minimum functions, The composition of the rules uses the maximum method, and the defuzzification uses the centroid of area method. Based on the results of the study, it shows that the Mamdani method is effectively used to predict the cost of electricity usage in Leuwimekar Village, Bogor City. For future research, it is recommended to be able to add other input variables related to output results, use other fuzzy logic methods which can then be compared with the results to find more effective methods, and can develop applications that utilize fuzzy logic systems with the Mamdani method on predicting electricity consumption costs.

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