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Analysis of Estimated Electricity Consumption of Medan City in 2024-2028 Using Fuzzy Mamdani Logic

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ABSTRACT

This research employs fuzzy linear programming with Mamdani fuzzy logic to predict electricity consumption in Medan City. Data from the Central Statistics Agency (BPS) for the years 2019-2023, including population, electricity customers, Gross Regional Domestic Product (PDRB), and electricity consumption, were analyzed quantitatively. Data processing involved fuzzification, rule formation, rule composition, and defuzzification, with simulations and testing conducted using MATLAB software. The research findings indicate a forecasting error rate of 1.514%, demonstrating effective performance in predicting electricity consumption. Elasticity analysis reveals that electricity consumption in Medan City is significantly influenced by PDRB, providing crucial insights for future energy planning.

Keyword: Mamdani Fuzzy Logic, Fuzzy Linear Programming, Electricity Consumption, PDRB, Medan City.

1. INTRODUCTION

Fuzzy logic, introduced by Lotfi Zadeh in 1965, has become a crucial concept in managing uncertainty and ambiguity in data and decision-making processes. Among the most popular methods in fuzzy logic is the Mamdani method. Developed by Ebrahim Mamdani in 1974, this method aims to solve complex control problems using rules based on fuzzy logic. Inspired by human decision-making processes, the Mamdani method allows systems to process fuzzy information and make appropriate decisions based on the given inputs.

The Mamdani method has been applied in various applications, including the prediction of electricity consumption. For instance, this research utilizes the Mamdani fuzzy logic method to predict electricity consumption in Medan City. Using data from the Central Statistics Agency (BPS) from 2019-2023, including population size, number of electricity customers, Gross Regional Domestic Product (PDRB), and electricity consumption, a quantitative analysis was conducted. The data processing process includes fuzzification, rule formation, rule composition, and defuzzification, with simulations and testing using MATLAB software. This approach illustrates how Mamdani fuzzy logic can effectively manage uncertain data and produce intuitively understandable outputs, making it a popular choice for complex decision-making applications.

2. METHODS

1.1. Research Design

The data used for this study were obtained from BPS for the years 2019-2023, containing information on population growth, number of customers, Gross Regional Domestic Product (PDRB), and the output in the form of electricity consumption. This research is quantitative in nature, employing a descriptive method. In quantitative research, data are typically expressed in numerical form, graphs, and utilize statistical formulas in their calculations. Quantitative research is structured, systematic, accurate, and planned. The descriptive method is used to describe or provide a general overview of the object under study using data or samples collected from relevant institutions without manipulation. The descriptive method aims to describe the research object and the research results.

1.2. Data collection

The data used for this research was obtained from the Central Bureau of Statistics (BPS) for the years 2019-2023. The data includes:

1. Population growth
2. Number of customers
3. Gross Regional Domestic Product (PDRB)
4. Electricity consumption and research results.

Table 1. Population of Medan City 2019-2023

Year	Male	Female	Total
2019	1.125.267	1.154.627	2.279.894
2020	1.212.069	1.223.183	2.435.252
2021	1.225.201	1.235.657	2.460.858
2022	1.242.313	1.252.199	2.494.512
2023	1.250.146	1.713.864	2.964.010

(Source: BPS, 2019-2023)

Table 2. Number of Electricity Customers in Medan City

No	Customer Type	2019	2020	2021	2022	2023
1	Household	340.439	357.373	352.852	361.769	359.475
2	Business	11.377	11.609	11.652	11.865	12.048

3	Industrial	153	154	137	160	163
4	Public	9.528	9.781	10.215	10.594	11.054
	Total	361.497	378.917	374.829	384.388	382.740

(Source: BPS, 2019-2023)

Table 3. Electricity Consumption in Medan City

Year	Installed Capacity	Electricity Production	Purchased/ Received electricity	Electricity Sold
2019	1.628.727	4.338.962	3.823.797	3.427.161
2020	1.710.807	4.552.465	3.904.036	3.473.774
2021	1.843.401	4.811.079	4.071.345	3.663.496
2022	1.946.430	4.960.465	4.226.466	3.827.361
2023	2.075.458	5.453.925	4.679.560	4.143.699

(Source: BPS, 2019-2023)

Table 4. PDRB of Medan City Based on Current Prices

Field of Business	**2019**	**2020**	**2021**	**2022**	**2023**
Agriculture, Forestry and Fisheries	2.692,14	2.695,32	2.502,90	2.675,75	2.818,56
Mining and Excavation	2,38	2,38	2,50	2,68	2,88
Manufacturing Industry	34.414,46	34.186,37	36.233,53	39.700,11	42.679,67
Provision of Electricity and Gas	221,61	233,49	249,46	265,10	279,92
Provision of Water, Waste Management and Recycling	457,86	489,55	507,70	528,47	556,38
Construction	46.722,92	45.610,72	49.099,95	53.504,94	56.404,83
Wholesale and Retail Trade, Repair of	61.710,08	62.278,30	66.287,25	73.541,94	80.787,61

Motor Vehicles and Motorcycles					
Transportation and Trading	15.395,34	14.136,93	14.121,61	16.446,01	19.037,94
Provision of Accommodation and Food and Beverage	7.351,23	6.619,81	6.554,29	7.454,45	8.604,06
Information and Communication	12.442,79	13.604,94	14.537,49	16.343,84	18.321,16
Financial and Insurance Services	14.668,09	14.547,51	15.529,46	16.856,17	17.660,96
Real Estate	21.459,98	23.032,95	23.713,70	25.330,01	26.262,54
Company Services	6.463,39	6.721,61	6.986,76	8.107,28	8.982,80
Admnistrasi Government Administration, Defense and Social Security Assurance	4.380,48	4.672,61	4.761,18	4.735,90	4.605,67
Education Services	6.150,11	6.262,52	6.468,63	6.753,01	7.350,57
Health and Social Activities	4.119,50	4.221,91	4.253,98	4.598,93	5.081,29
Other Services	2.830,00	2.882,48	2.921,58	3.314,46	3.875,03
PDRB	241.482,35	242.198,84	254.721,96	280.159,04	303.311,88

(Source: BPS, 2019-2023)

3. RESULT AND DISCUSSIONS

3.1 Data analysis

The data analysis stage is crucial in system development because it involves evaluating existing problems, designing the system, and determining the necessary steps to achieve the desired outcomes. Data from 2019 to 2023 provides valuable insights into the trends of key variables impacting electricity consumption in Medan City: population growth, number of electricity customers, Gross Regional Domestic Product (GRDP), and actual electricity consumption figures. The Compound Annual Growth Rate (CAGR) method was utilized to forecast the population, number of electricity customers, and GRDP for the period from 2024 to 2028.

Additionally, the Mamdani fuzzy inference system was employed to predict electricity consumption and compare its accuracy with the CAGR method using Mean Absolute Percentage Error (MAPE)

3.2 Process Analysis

In this phase, the data from 2019 to 2023 was analyzed using the Compound Annual Growth Rate (CAGR) method to forecast key variables, such as population growth, number of electricity customers, and Gross Regional Domestic Product (GRDP) for the period from 2024 to 2028. These forecasts provide essential insights into the expected trends of these variables, which are crucial for predicting future electricity consumption in Medan City.

Table 5. Predicted Results For Each Variable by CAGR

No	Category	2024	2025	2026
1.	Population	3.162.996,61	3.379.575,62	3.608.721,95
2.	Number of Customer	388.243,01	393.825,13	399.487,52
3.	PDRB	321.100,09	339.931,52	359.867,35
4.	Electricity Consumption	4.345.118,49	4.556.328,70	4.777.805,55

(Source: MATLAB Calculation)

Table 6. Predicted Results For Each Variable by CAGR

No	Category	2027	2028
1.	Population	3.853.405.15	4.114.678,67
2.	Number of Customer	405.231,32	411.057,71
3.	PDRB	380.972,34	403.315,07
4.	Electricity Consumption	5.010.048,08	5.253.579,61

(Source: MATLAB Calculation)

3.3 Fuzzification

Fuzzification is a crucial step in converting crisp input data into fuzzy sets based on linguistic variables. In this study, the Mamdani fuzzy inference system was applied to predict electricity consumption for the period 2024-2028. The inputs to the Mamdani system were fuzzy sets derived from the forecasted values of population growth, number of electricity customers, and Gross Regional Domestic Product (GRDP) using the Compound Annual Growth Rate (CAGR) method. These fuzzy sets were defined using triangular membership functions to represent the linguistic variables: Low, Medium, and High, based on historical data from 2019 to 2023.

Table 7. Predicted Results for Each Variable by CAGR

Function	**Variable**	**Semesta Pembicaraan**
Input	Population	3.100.000 – 4.200.000

	Number of Customer	380.000 – 410.000
	PDRB	320.000 – 400.000
Output	Electricity Consumption	4.300.000 – 5.300.000

3.4 Analysis for Population Variables

The population variable has values expressed as low, medium, and high conditions, where each condition has a predetermined range of values. The range of values is set from the lowest value of 3.100.000 to the highest value of 4.200.000. The fuzzy set for Population is shown in the following table:

Table 8. Fuzzy Set for Population Variable

Variable	Fuzzy Set	Range
Population	Low	3.100.000 – 3.650.000
	Medium	3.350.000 – 3.950.000
	High	3.650.000 - 4.200.000

From the fuzzy membership diagram, the equation of the population fuzzy set can be seen:

$$\mu_r(low) = \begin{cases} 1 \,;\, a \leq 3.100.000 \\ \dfrac{3.650.000 - a}{3.650.000 - 3.100.000} \,;\, 3.100.000 < a < 3.650.000 \\ 0 \,;\, a \geq 3.650.000 \end{cases}$$

Moderate fuzzy set equation

$$\mu_r(moderate) = \begin{cases} \dfrac{a - 3.350.000}{3.650.000 - 3.350.000} \,;\, 3.350.000 \leq a < 3.650.000 \\ \dfrac{3.950.000 - a}{3.950.000 - 3.650.000} \,;\, 3.650.000 < a < 3.950.000 \\ 0 \,;\, a \leq 3.350.000 \; atau \; a \geq 3.950.000 \end{cases}$$

Shiny fuzzy set equation

$$\mu_r(Shiny) = \begin{cases} 0 \,;\, a \leq 3.650.000 \\ \dfrac{a - 3.650.000}{4.200.000 - 3.650.000} \,;\, 3.650.000 < a < 4.200.000 \\ 1 \,;\, a \geq 4.200.000 \end{cases}$$

3.5 Analysis for Number of Customer Variable

The number of customers variable has values expressed in low, medium, and high conditions, where each condition has a predetermined range of values. The range of values is set from the lowest value of 380.000 to the highest value of 410.000. The fuzzy set for the Number of Customers is shown in the following table:

Table 9. Fuzzy Set for Number of Customer Variable

Variable	Fuzzy Set	Range
Number of	Low	380.000 – 395.000
Customer	Medium	387.500 – 402.500
	High	395.000 - 410.000

From the fuzzy membership diagram, the equation of the fuzzy set "low" can be observed:

$$\mu_r(low) = \begin{cases} 1 \,;\, a \leq 380.000 \\ \dfrac{a - 380.000}{395.000 - 380.000} \,;\, 380.000 < a < 395.000 \\ 0 \,;\, a \geq 395.000 \end{cases}$$

The equation of the fuzzy set "medium":

$$\mu_r(medium) = \begin{cases} \dfrac{a - 387.500}{395.000 - 387.500} \,;\, 387.500 \leq a < 395.000 \\ \dfrac{402.500 - a}{402.500 - 395.000} \,;\, 395.000 \leq a \leq 402.500 \\ 0 \,;\, a \leq 387.500 \;\; or \;\; a \geq 402.500 \end{cases}$$

The equation of the fuzzy set "high":

$$\mu_r(high) = \begin{cases} 0 \,;\, a \leq 395.000 \\ \dfrac{a - 395.000}{410.000 - 395.000} \,;\, 395.000 \leq a \leq 410.000 \\ 1 \,;\, a \geq 410.000 \end{cases}$$

3.6 Analysis for PDRB Variable

The GRDP variable has values expressed in low, medium, and high conditions, where each condition has a predetermined range of values. The range of values is set from the lowest value of 320.000 to the highest value of 400.000. The fuzzy set for GRDP is shown in the following table:

Table 10. Fuzzy Set for PDRB Variable

Variable	Fuzzy Set	Range
PDRB	Low	320.000 – 360.000
	Medium	340.000 – 380.000
	High	360.000 - 400.000

From the fuzzy membership diagram, the equation of the fuzzy set "low" can be observed:

$$\mu_r(low) = \begin{cases} 1 \,;\, a \leq 320.000 \\ \dfrac{360.000 - a}{360.000 - 320.000} \,;\, 320.000 < a < 360.000 \\ 0 \,;\, a \geq 360.000 \end{cases}$$

The equation of the fuzzy set "medium":

$$\mu_r(medium) = \begin{cases} \dfrac{a - 340.000}{360.000 - 340.000} \,;\, 340.000 \leq a < 360.000 \\ \dfrac{380.000 - a}{380.000 - 360.000} \,;\, 360.000 \leq a \leq 380.000 \\ 0 \,;\, a \leq 340.000 \;\; or \;\; a \geq 380.000 \end{cases}$$

The equation of the fuzzy set "high":

$$\mu_r(high) = \begin{cases} 0 \,;\, a \leq 360.000 \\ \dfrac{a - 360.000}{400.000 - 360.000} \,;\, 360.000 < a < 400.000 \\ 1 \,;\, a \geq 400.000 \end{cases}$$

3.7 Analysis for PDRB Variable

The electricity consumption variable has values categorized into low, medium, and high conditions, with each condition having a predetermined range of values. The range spans from the lowest value of 4.300.000 to the highest value of 5.300.000. The fuzzy set for electricity consumption is shown in the following table:

Table 11. Fuzzy Set for Electricity Consumption Variable

Variable	Fuzzy Set	Range
Electricity	Low	4.300.000-4.800.000
Consumption	Medium	4.550.000-5.505.000
	High	4.800.000-5.300.000

From the fuzzy membership diagram, the equation of the fuzzy set "low" can be observed:

$$\mu_r(low) = \begin{cases} 1\,; a \leq 4.300.000 \\ \dfrac{4.800.000 - a}{4.800.000 - 4.300.000}\,; 4.300.000 < a < 4.800.000 \\ 0\,; a \geq\ 4.800.000 \end{cases}$$

The equation of the fuzzy set "medium":

$$\mu_r(medium) = \begin{cases} \dfrac{a - 4.550.000}{4.800.000 - 4.505.000}\,; 4.550.000 \leq a < 4.800.000 \\ \dfrac{5.505.000 - a}{4.800.000 - 4.505.000}\,; 4.800.000\ \leq a \leq 5.505.000 \\ 0\,; a \leq 4.550.000\ \ or\ \ a \geq 5.505.000 \end{cases}$$

The equation of the fuzzy set "high":

$$\mu_r(high) = \begin{cases} 0\,; a \leq 4.800.000 \\ \dfrac{a - 4.800.000}{5.300.000 - 4.800.000}\,; 4.800.000 < a < 5.300.000 \\ 1\,; a \geq 5.300.000 \end{cases}$$

3.8 Process Analysis Fuzzy Logic

The next step involves calculations using the Mamdani fuzzy method. By utilizing CAGR data, particularly for the variables Population, Number of Customers, and GRDP, we aim to predict the electricity consumption values. The Mamdani method was implemented using MATLAB, and the results are as follows:

Table 12. Forecasted Values for Each Variable Using Mamdani Method

No	Category	2024	2025	2026
1.	Population	3.162.996,61	3.379.575,62	3.608.721,95
2.	Number of Customer	388.243,01	393.825,13	399.487,52
3.	PDRB	321.100,09	339.931,52	359.867,35
4.	Electricity Consumption	4.345.118,49	4.556.328,70	4.777.805,55

(Source: MATLAB Calculation)

Table 13. Forecasted Values for Each Variable Using Mamdani Method

No	Category	2027	2028
1.	Population	3.853.405.15	4.114.678,67
2.	Number of Customer	405.231,32	411.057,71
3.	PDRB	380.972,34	403.315,07
4.	Electricity Consumption	5.010.048,08	5.253.579,61

(Source: MATLAB Calculation)

3.9 Simulation Using MATLAB

After obtaining the forecast results, the accuracy of the Mamdani Fuzzy Logic forecast can be calculated using the Mean Absolute Percentage Error (MAPE). This involves comparing the forecast results with actual data as per equations (14) and (15). The forecast accuracy calculation using MAPE in this case is conducted with MATLAB. The program executed is as follows:

```
% Actual and predicted data
actual = [4345118.49, 4556328.70, 4777805.55, 5010048.08, 5253579.61];
       predicted = [4300000, 4500000, 4662403.3333, 4887541.0135,
5276425];
% Calculate absolute error
absolute_error = abs(actual - predicted);

% Calculate percentage absolute error
percentage_error = absolute_error ./ actual;

% Calculate MAPE (Mean Absolute Percentage Error)
mape = mean(percentage_error) * 100;
disp(['MAPE: ', num2str(mape), '%']);
```

Output:

MAPE: 1.514%

As observed from the MATLAB output, the MAPE value is 1.514%. A model's performance is considered excellent if the MAPE is below 10%, and good if it is between 10% and 20%. Thus, the forecasting using the Mamdani fuzzy method can be classified as having excellent performance.

3.10 Calculation of Energy Elasticity

After obtaining the forecasted growth in electricity consumption and GRDP growth percentages per year, the electricity elasticity in Medan City can be calculated using equation (16). Using MATLAB, the results are as follows:

```
% Data konsumsi energi listrik
Q = [4300000, 4500000, 4662403.3333, 4887541.0135, 5276425];
% Data PDRB
P = [321100.09, 339931.52, 359867.35, 380972.34, 403315.07];
% Menghitung pertumbuhan konsumsi energi listrik
delta_Q = diff(Q);
Q1 = Q(1:end-1);
Q2 = Q(2:end);
% Menghitung pertumbuhan PDRB
delta_P = diff(P);
P1 = P(1:end-1);
P2 = P(2:end);
% Menghitung elastisitas energi listrik
Ed = (delta_Q ./ (Q1 + Q2)) ./ (delta_P ./ (P1 + P2));
% Menampilkan hasil
disp('Elastisitas energi listrik:');
disp(Ed);
```

Output:

Electricity elasticity:

0.79780.6222 0.8275 1.3431

Based on the results obtained, it can be observed that in one period, the electricity elasticity is relatively high (greater than 1), indicating that in that period, electricity demand is very responsive to changes in GRDP. In other periods, the electricity elasticity is relatively low (less than 1), indicating that during those periods, electricity demand is less responsive to changes in GRDP. The Mamdani method forecasting in this study is categorized as a very good forecasting method with an error rate of 1.514%. As per the forecast, the electricity consumption in Medan City is relatively high, which in the future will be influenced by the city's GRDP.

4. CONCLUSION

Based on the research conducted, several conclusions can be drawn as follows: The forecasted electricity consumption shows an annual increase from 2024, starting at 4,300,000 Wh, and rising to 976,425 Wh by 2028. The increase in electricity consumption over five years is 22.707%. The accuracy comparison between actual data and forecasted electricity consumption using the Mamdani Fuzzy Logic method yields a Mean

Absolute Percentage Error (MAPE) of 1.519% for Medan City from 2024 to 2028. Based on the MAPE value, the Mamdani Fuzzy Logic method is considered very good for predicting electricity consumption in Medan City. The energy elasticity in Medan City shows a value of 1.341. This figure indicates that the electricity consumption in Medan City is relatively high, which in the future will be influenced by the city's GRDP.

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