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Analysis of Causality and Forecasting between Electricity Consumption and Economic Growth in Indonesia

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Abstract
The main objective of this study is to examine relationship between electricity consumption from 4 sectors which are household, commercial, industrial, transportation toward economic growth using data from 2001 to 2023 by applying the autoregressive distributed lag (ARDL) model. Other variables such as capital and labor that affect economic growth are also added. Data obtained from the Central Bureau of Statistics, World Bank. To see the relationship between variables, a Granger causality test is carried out. Modeling using the ARDL method is used to see long-term and short-term relationships. Furthermore, forecasting is also carried out to see the achievement of economic growth targets. The findings that commercial electricity consumption, industrial electricity consumption, transportation electricity consumption have a one-way causal relationship with economic growth or the growth hypothesis accepted. While household electricity consumption does not have a causal relationship with economic growth. Based on the ARDL method, there is a long-term relationship. Electricity consumption scenario of each sector can achieve the economic growth target with the household sector 20.4%, commercial 8.9%, industry 40% and transportation 28.3%. and constant capital growth of 2% per year, average increase in the number of workers of 2% per year.
Keywords: *energy economic; economic growth; electricity consumption;*

INTRODUCTION

Although economic theories do not define the relationship between energy consumption—particularly electricity—and economic growth, many studies suggest that electricity consumption is crucial for economic and a key indicator of social development. It can drive economic growth (Mutumba et al, 2024) by enhancing capital (Wahyudi & Palupi, 2023) labor (Meydani & Ghomi ,2019), and technology innovation (Tan, 2013). An increase in energy needs occurs due to population growth and industrialization (Mombekova. et al, 2024).

Energy is an important factor in the production process. Energy is also claimed to play an important role in economic development (Sa'adaha, 2017). Electrical energy is one type of energy that has an important and strategic role in human life. The rapid development of the economy is also followed by an increase in electricity consumption in various sectors.

The demand for electricity has increased in the industrialization era because electricity is the main source of energy in the production process (Ateba & Gawlik, 2019). An increase in electricity consumption is claimed to encourage the development of industry in producing output, especially in the processing industry (Thaker. et.al, 2019) which will ultimately contribute to GDP (Basconcillo & Rimkute, 2023). In addition to the industrial sector, electricity consumption in the household sector also plays an important role in economic growth, improving living standards and energy policy makers (Zhang. et.al, 2017).

Wijaya (2023) in the study conducted using the OLS estimation method with control variables in the form of investment, real interest rates and inflation found that electricity

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consumption in the industrial sector was found to have an influence on increasing output, especially in the processing industry. Electricity and economic growth were found to have a one-way relationship by Rahman (2023) who analyzed using the FMOLS and DOLS methods.

By analyzing data from 1971-2013, Rahman, (2023) research, in addition to looking at economic growth and electricity consumption, also links environmental variables proxied by CO2. Other findings in this study confirm the Environmental Kuznets Curve (EKC) hypothesis about the two-way relationship between economic growth and electricity consumption as well as electricity consumption and CO2 in the countries used as research samples. The significant unidirectional influence between electricity consumption and economic growth was also revealed in the research of Sapthu (2023) using a regression model. The results of the study stated that increased productivity is supported by electricity supply so that efficient production of goods and services also increases.

The high level of electricity consumption is also said to be able to encourage investment in energy infrastructure which in turn can stimulate economic growth. Unlike other researchers, Korra (2017) using the ADRL method found a long-term relationship between the variables he studied. Then a two-way relationship also occurs between economic growth and energy consumption, both petroleum, natural gas and renewable energy. The one-way relationship that meets the growth hypothesis is only found in coal energy consumption. In his study, he also revealed that capital and labor have contributed to Indonesia's economic growth.

However, Sari (2022) using the same method found an insignificant relationship in the long and short term between electricity consumption and economic growth. Given the potential contribution of electricity consumption to economic growth, several researchers have conducted in-depth investigations and found positive results between the two variables, for example research conducted in China (Thaker. et.al, 2019) and in Malaysia (Sari, 2022).

In Indonesia, various findings were also obtained, such as there was no significant relationship between electricity consumption and economic growth in either the long or short term (Sapthu, 2023). Then, there are also findings that state a significant influence between variables and strong electricity consumption can encourage investment in the infrastructure sector so that it can stimulate economic growth (Rahman, 2020) and the finding of a one-way relationship between economic growth and electricity consumption (Komarova. et.al, 2022).

The results of other studies reveal that the impact of energy consumption on the economy is identified as stronger in countries that are members of the non-OECD including the Asia-Africa Region (Mombekova. et.al, 2024). However, a decrease in energy consumption does not always cause low economic growth in a country. When energy consumption decreases but on the other hand a country's GDP per capita increases, it means that there is an energy transition that shifts towards efficiency (Richard & Koomey, 2015).

The ratio of energy consumption per unit of economic activity that increases and then experiences a faster decline indicates wiser use of energy (Komarova. et.al, 2022). Therefore, determining the relationship between energy consumption and economic growth accurately can be a very important input of information for policy makers to make strategic decisions related to energy consumption (Mixsindo, 2017). Based on the literature above, this study contains the development of previous research which will look at the relationship between input in the form of energy consumption, capital and labor to GDP as output in the long and short term, as well as forecasting economic growth by adjusting the target energy needs for user sector.

Based on the Statistical Energy & Economic Statistics Book 2016 and 2023 Data for 2000-2023, electricity in Indonesia is mostly consumed by the household, industrial, commercial and transportation sectors as presented in Figure 1. RUEN No.22/2017 states that the target energy needs in 2025 for the industrial sector are projected at 47.6%, transportation 30.3%, Household 15%, Commercial 4.9%.

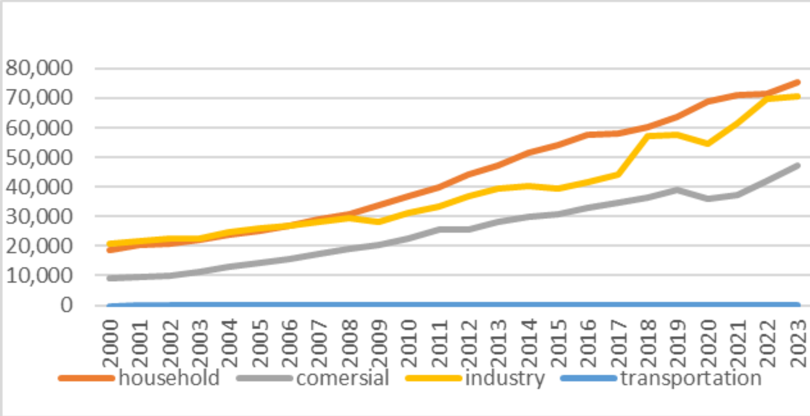


Figure 1. Electricity Consumption by Sectors
Source: BPS (2023)

RESEARCH METHOD

This study used 2 types of methods to achieve the research objectives. The first method is Granger causality analysis. The second method used is the ARDL method to predict the impact of electricity consumption on economic growth in Indonesia. The results of the Granger causality test are the direction of the relationship between the independent variables and the dependent variables, whether they are unidirectional, bidirectional or have no relationship. The econometric model in the study was built based on the Cobb-Douglas production function approach,

$$Y = f\,(Ec, C, L) \qquad (1)$$

The dependent variables in this study are Indonesia's gross domestic product as output and electricity consumption, capital, labor force as input factors as well as independent variables in the function. All variables are formulated using the ARDL method. After the model is formed, the next step is to conduct a cointegration test using the bound test and Johansen test to determine the long-term and short-term relationships between variables. The model built is also used for energy growth forecast projections based on electricity consumption. Testing and forecasting are carried out using the help of Eviews software. This study uses time series data from 2000-2023.

RESULTS AND DISCUSSIONS

The first part is the result of the analysis of the causality between energy consumption and the second result is the econometric model of the relationship between energy consumption and economic growth in Indonesia in the short and long term and the third part is the result of forecasting economic growth according to the energy needs scenario. From the results of the causality test in this study, it is known that the consumption of electricity in the industrial, transportation and commercial sectors has a one-way (unidirectional) causal relationship with economic growth.

This means that if there is a change in the electricity consumption of the industrial, transportation and commercial sectors, it will also change GDP so that the relationship between electricity consumption of the three sectors in this study meets the growth hypothesis. However, the household electricity consumption variable does not have a causal relationship with economic growth in Indonesia. These results support the research by Ramadayanti, et al (2018) which states that Economic Growth does not have a significant effect on Household Sector Energy Consumption in Indonesia. In addition, it is also known that there are several electricity consumption variables that have a causal relationship with other independent variables such as capital (Boamah. et al, 2018) but none of the energy consumption variables have a causality with the labor force variable.

Before conducting the cointegration analysis, the time series properties of the series were checked first. Various methods can be used to examine the stationarity or otherwise of the series. In this study, three different unit root tests were employed to have robust results. These are Augmented Dickey-Fuller (ADF). The tests are conducted at the level and first difference with trend and intercept. The Augmented Dickey-Fuller (ADF) unit root tests have a null hypothesis stating that the series in question has a unit root against the alternative that the variable does not have a unit root.

From Table 1, the unit root test reveals that in levels all variables are not stationary, and at their first difference both test show that all variables are stationary at 5% and 10% significant level, except residential sector (RE). ARDL estimates are dynamically and structurally stable, consistent, and reliable.

Based on Figure 1, through the cumulative sum of the recursive residual (CUSUM) and the cumulative sum of the squares of recursive residuals (CUSUMSQ) test, the graphical result that residual were within the critical bounds at 5% level of significant.

Table 1. Results of Various Unit Root Tests with Trend and Intercept

ADF Unit Root Test at Level			ADF Unit Root Test at First Difference	
Variables	T statistic	Probability	T statistic	Probability
Y	-0.287926	0.9126	-3.557054	0.0159**
X1	1.664197	0.9992	-3.086982	0.0424**
X2	0.689835	0.9884	-3.710222	0.0128**
X3	3.761051	1.0000	-4.658790	0.0015*
X4	2.111492	0.9998	-3.615545	0.0140**
X5	-0.222023	0.9213	-5.104687	0.0006*
X6	0.184634	0.9653	-4.344241	0.0028*

Source: Author's Computation, 2025

Table 1 presents the unit root tests using ADF indicate that all variables were stationary at the frist difference at a 1% and 5% significance levels. Therefore, an examination of Table 1 reveals that the series are a mixture of the order of integration as some variables were stationary at the first difference and are thus characterized as I (1) processes, while others were stationary at the level and are thus characterized as I (0) process.

This mixture of I (1) and I (0) processes justified using the ARDL model in this research to check the cointegration due to its advantage over other estimators. As one of the requirements for using the ARDL model is that some variables should be I(0) while other variables should be I(1), and none of the variables should be I(2). Since the variables were found to have characteristics of both I(0) and I(1), the next step of the study estimates the short-run and long-run elasticity based on the optimal lag model ARDL Model19 (1,2,2,2,0,2,2) selected using the Akaike information criterion shown in figure 2 bellow.

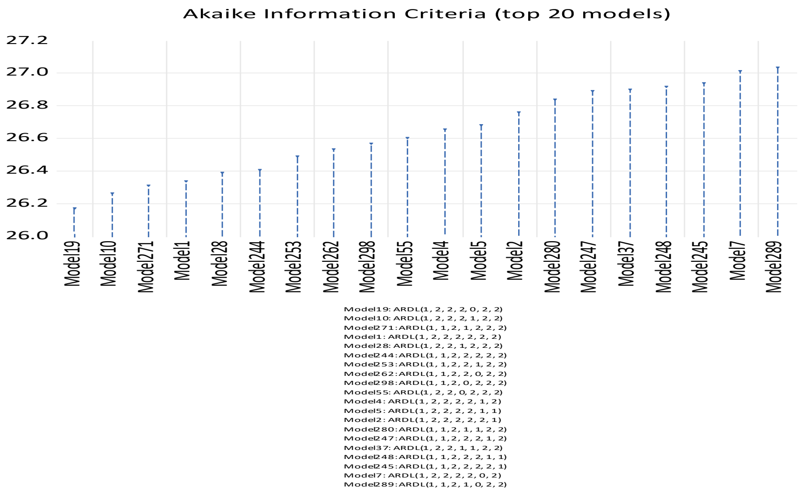


Figure 1. Akaike Information Criterion
Source: Author's Computation, 2024

Table 2. Bond Test Result

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	6.591805	10%	1.99	2.94
K	6	5%	2.27	3.28
		2.5%	2.55	3.61
		1%	2.88	3.99

Note: *Denotes rejection of the null hypothesis at a 1% significance level
Source: Author's Computation, 2025

After selecting the optimal lag model for the ARDL regression analysis, this research examines the cointegration among the variables using the ARDL bounds test based on the null hypothesis of no long-run relationship. Evidence from Table 2 shows that the F-statistic value (6.59> I1 Bound) lies above the upper bound critical values at 10%, 5%, 2.5%, and 1%, rejecting the null hypothesis of no long-run relationship exists at the 1% level of significance and concluded that, the variables under study are cointegration in the long run. Table 3 presents result both of short-run and long-run dynamics of the ARDL model.

Table 3. ARDL Cointegration Result
Cointegration Form

Variable	Coefficient	Std.Error	t-Statistic	Prob.
D(X1(-1))	-91.54558	5,828,502	-1,570,654	0,2143
D(X2(-1))	601.8594	1,122,722	5.3607 18	0,0127**
D(X3(-1))	1.290,800	5,598,739	2,305,519	0,1045
D(X4)*	-2,350,718	8,480,104	-2,772,039	0,0695***
D(X5(-1))	0,274,437	0,089,837	3,054,847	0,0552***
D(X6(-1))	-2.43E-05	2.11E-05	-1,150,978	0,3332
D(X1,2)	-225.896 1	72.840 16	-3,101,257	0,0532***
D(X1(-1),2)	-1,392,060	1,054,267	-1,320,406	0,2784
D(X2,2)	1,542,468	4,525,586	3,408,329	0,0422**
D(X2(-1),2)	-5,342,321	8,903,929	-5,999,959	0,0093*
D(X3,2)	-98.8 1236	39.407 13	-2,507,474	0,0871***
D(X3(-1),2)	-1,702,954	7,245,875	-2,350,239	0,1003
D(X5,2)	0.191025	0,041,884	4,560,768	0,0198**

Variable	Coefficient	Std.Error	t-Statistic	Prob.
D(X5(-1),2)	-0,222,173	0,074,634	-2,976,848	0,0587***
D(X6,2)	5.46E-05	2.48E-05	2,200,337	0,1151
D(X6(-1),2)	6.58E-05	1.21E-05	5,413,379	0,0124**
C	-4,830,208	2233 14.1	-2,162,966	0,0119**

Source: Author's Computation, 2025

The results shown the best model from the Autoregressive Distributed Lag (ARDL) test is the ARDL model (1,2,2,2,0,2,2). Coefficient of electricity consumption in the household sector in first past (X1-1) has no significant effect on economic growth but in the second past year (X1-2) has a significant effect in the short term on economic growth.

The coefficient of X2 (electricity consumption in commercial sector) in the first and second past has a significant effect. The coefficient of electricity consumption in the industrial sector in the first past year has no significant effect but in the second past year it is significant on economic growth. The coefficient of electricity consumption in the transportation sector has a significant effect on economic growth. The coefficient of labor in the first past has no effect while in the second past it has a significant effect on economic growth. The coefficient of capital has a significant effect on economic growth in the first past and the second past in the short term.

Table 4. Long Run Coefficients

Variable	Coefficient	Std.Error	t-Statistic	Prob.
D(X1)	-125.096 1	8,995,534	-1,390,647	0,2585
D(X2)	8,224,347	2,435,043	3,377,496	0,0432**
D(X3)	1,763,865	83.586 16	2,110,235	0,1253
D(X4)	-3,212,232	1,069,026	-3,004,822	0,0574***
D(X5)	0.3750 15	0,104,254	3.597 122	0,0368**
D(X6)	-3.32E-05	3.23E-05	-1,027,439	0,3798
C	-6.600,430	2,797,752	-2.359 190	0,0995***

Source: Author's Computation, 2025

Based on the results of the ARDL model estimation in the long term, it can be explained that variables of Household Sector Electricity Consumption (X1) and the industrial sector (X3) statistically do not have significant values on economic growth in the long term. The variables of Commercial Sector Electricity Consumption (X2) and the transportation sector (X4) have significant values in the long term on economic growth. Furthermore, labor force (X5) in the long term has significant value on economic growth but not for capital (X6) in the long term.

After estimating the ARDL regression, the next step is to determine the appropriateness of the ARDL model. The study conducts some diagnostic tests (e.g., serial correlation, heteroscedasticity, and normality tests) and parameter stability tests to examine the "independence" of the residuals in the ARDL model.

Harvey Heteroskedasticity Test to test for Heteroskedasticity problems, the Breusch–Godfrey Serial Correlation LM Test to push for serial correlation, and the Jarque–Bera Test to test for normality of the variables. Evidence from Table 4 reveals that the residuals in the ARDL model have no Heteroskedasticity problems, exhibit no serial correlation, no misspecification (i.e., in its functional form), and are typically distributed. These tests show in Table 5 and Figure 6 below.

Table 5. Post Estimation Test

Diagnostics Check	STATISTIC	Prob.	Null Hypotheses
Heteroskedasticity Test	0.291353	0.7309	No Heteroskedasticity
Breusch-Godfrey Serial Correlation LM Test	0.465415	0.4530	No Serial correlation

Source: Author's Computation, 2025

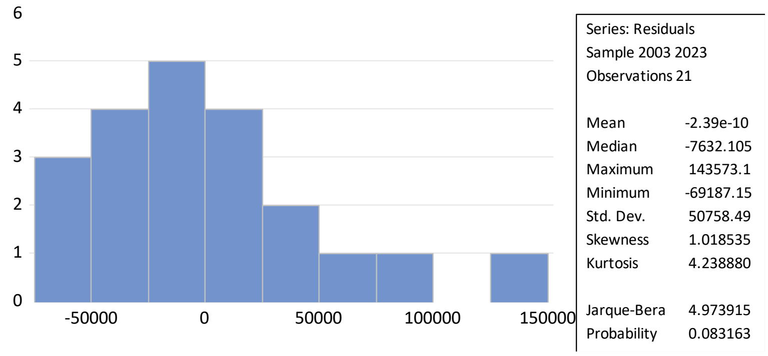


Figure 2. Normality Test's Result
Source: Author's Computation, 2025

To check the stability and adequacy of the ARDL approach, the research analyses the reliability of the cointegration by using Cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ) Tests. As mentioned in the methodology, the cumulative sum (CUSUMSQ) test tests the andomness of a sequence of zeros and ones (Data plot to convert a data set with exactly two distinct values to a series of zeros and ones).

For this test, the zeros to negative ones. The test is based on the maximum distance from zero of a random walk defined by the cumulative sum of the sequence. An ample enough space is indicative of nonrandomness, while the cumulative sum of squares (CUSUMSQ) tests are based on the recursive regression residuals. Figure 7 reveals that both CUSUM and CUSUM of squares are within the 5% significance level; thus, ARDL model is robust, stable, and adequate in its form.

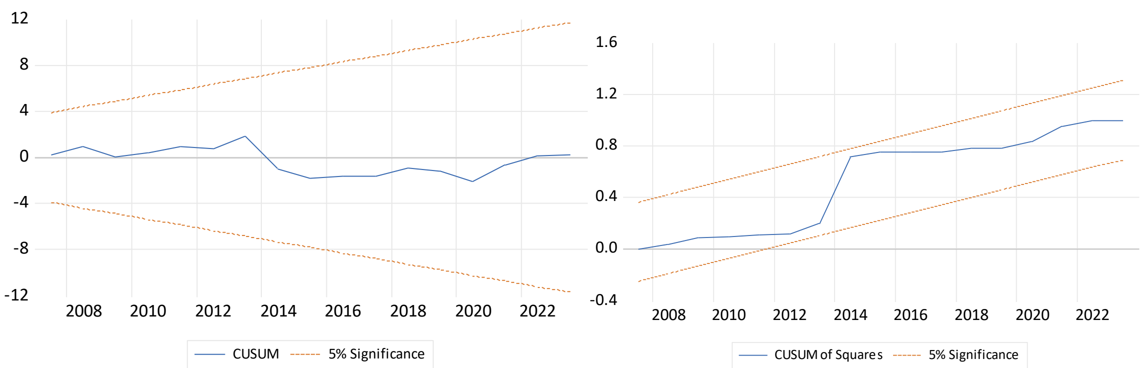


Figure 3. Stability Test's Result
Source: Author's Computation, 2025

Forecasting results of the ARDL model (1,2,2,2,0,2,2) shows that the values of energy, capital and labor force variables are obtained which are accumulated to obtain the GDP growth value. Based on the cumulative results, the contribution of energy variables during the period 2000-2023 has an increasing trend. A significant decline was observed only in 2020, because of Covid-19 in Indonesia.

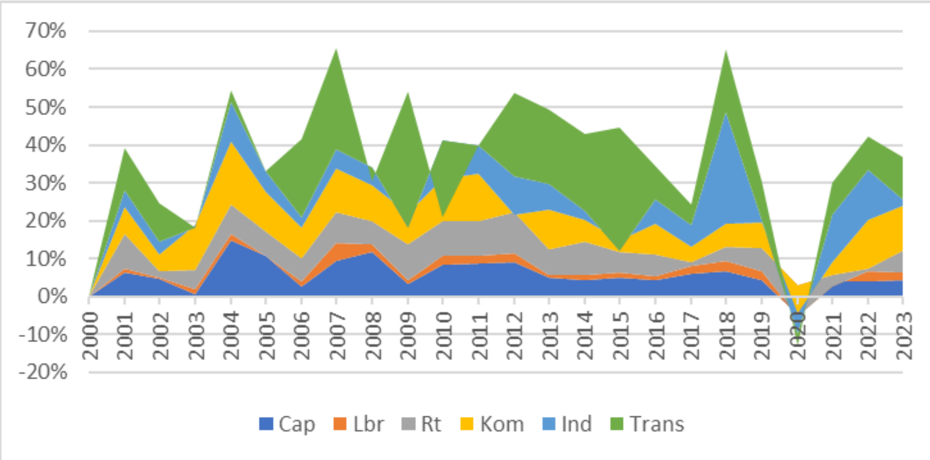
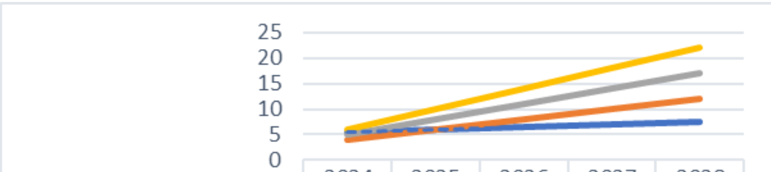


Figure 4. Cumulative percentage contribution of energy, capital and labor variables to GDP
Source: Author's Computation, 2025

Furthermore, the research scenario for forecasting GDP growth in the period 2024-2028 is carried out by adjusting RUEN No. 22/2017 for the electricity consumption variable in each sector. For forecasting capital variables, the assumption of fixed capital growth is used each year. Forecasting labor variables uses labor force growth. Capital growth is projected to be constant based on the average capital in 2000-2023. The average capital growth during this period is 6%. In this study, calculations were made based on a capital growth scenario increasing by 2%-4% from the average capital growth.



	2024	2025	2026	2027	2028
Target PDB	5.5	6	6.5	7	7.5
kapital tumbuh 2%	4.05	6.05	8.05	10.05	12.05
kapital tumbuh 3%	5.05	8.05	11.05	14.05	17.05
Kapital tumbuh 4%	6.05	10.05	14.05	18.05	22.05

Figure 5. Achievement of economic growth targets based on scenario
Source: Author's Computation, 2025

The final energy consumption target for each sector prepared by the government until 2025 can achieve the economic growth target. Based on the research, the scenario for each sector to achieve the economic growth target is the proportion of the household sector 20.4%, commercial 8.9%, industry 40% and transportation 28.3%.

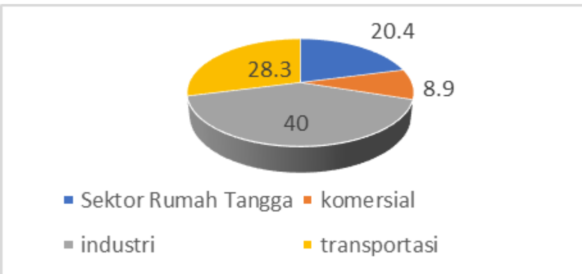


Figure 6. Energy Consumption by sectors scenario
Source: Author's Computation, 2025

CONCLUSIONS

Based on the research results, this study is finding cointegration between the variables of electricity consumption in commercial, industrial and transportation sectors to GDP in one-way relationship or growth hypothesis. The causality between capital and economic growth also finding in one-way. During the period 2000-2023, capital has a higher contribution than labor force. Then, the contribution of energy also exceeds labor force. The economic growth target up to 2025, if only referring to the proportion of energy consumption in RUEN No. 22/2017 without being followed by capital growth, has not been achieved.

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