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# National Energy Security: An Analysis of Economic Growth and Energy Consumption at the Regional Level in Indonesia

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***Abstract.*** Regional energy security is a critical component in ensuring sustainable development in Indonesia, a country with diverse geographical and economic characteristics. In 2022, more than half of Indonesia's final energy consumption was concentrated in the Java-Bali region, highlighting regional disparities in energy use. This study aims to analyze the relationship between regional energy consumption and economic growth across Indonesia's major islands – Sumatra, Java, Bali & Nusa Tenggara, Sulawesi, and Maluku & Papua. Specifically, the study tests three main hypotheses: the growth hypothesis (energy consumption drives economic growth), the conservation hypothesis (economic growth leads to increased energy consumption), and the neutrality hypothesis (no significant causality between the two). Using panel data and the Granger Causality test technique, the study categorizes regional behavior to identify specific patterns of causality. The results support the growth hypothesis in most regions, where increased energy consumption, particularly electricity usage, significantly contributes to regional economic growth. In Bali & Nusa Tenggara, where the economy relies heavily on tourism and services, the conservation hypothesis is more applicable, suggesting that economic activity drives energy demand. In contrast, the Maluku & Papua region exhibits the neutrality hypothesis, with weak or no causal relationship between energy consumption and economic growth. These findings offer both theoretical and practical implications: they reinforce the importance of regional energy planning in economic policy and highlight the need for tailored energy strategies to suit the specific dynamics of each region. Understanding these regional patterns provides essential input for policymakers to design equitable and efficient energy distribution frameworks.

***Key words:*** energy security; economic growth; energy consumption; Granger causality; neutrality hypothesis.

**JEL** O14, P28, Q43

## 1. Introduction

Energy serves as a fundamental pillar for achieving sustainable economic growth and social advancement. It plays a critical role in maintaining the smooth functioning of both economic and social systems [1, 2]. Moreover, energy is an essential input for various production and consumption processes that contribute to economic expansion. Typically, economic growth leads to higher energy demand [3]. Although Indonesia has entered a phase of high-quality economic development and experienced a notable decline in energy intensity, the overall volume of energy consumption continues to rise [4].

Final energy consumption in 2022 continues to increase after plummeting in 2020 due to the COVID-19 pandemic. In 2022, final energy consumption reached

160.3 million TOE or grew by around 4.4 percent per year during the period 2013–2022. In 2022, the largest final energy consumption is the industrial sector, which is around 45 percent, followed by the transportation sector at around 37 percent [5]. The increase in energy consumption in the industrial sector is influenced by the increase in coal consumption, including the beginning of the development of the smelter industry. Meanwhile, energy consumption in the household sector is around 13 percent, commercial is around 4.2 percent and other sectors (agriculture, mining and construction) are around 1 percent.

Based on regional division, final energy consumption in 2022 is still concentrated in the Java-Bali region, which accounts for 54 percent of Indonesia's total final energy consumption [6]. Furthermore, the Sumatra region is 23 %, Kalimantan 14 percent, Sulawesi 6 percent, Nusa Tenggara 2 percent, Papua 1.1 percent, and Maluku around 0.9 percent. This figure is in line with the distribution conditions of the Indonesian population which is 58 percent domiciled in the Java-Bali region, and 22 percent in the Sumatra region and the rest are spread across the Kalimantan, Nusa Tenggara, Maluku and Papua regions.

Investigating the link between energy consumption and GDP has become increasingly crucial amid the global shift toward a low-carbon energy future and Indonesia's efforts to cut carbon emissions [7]. A common strategy to lower emissions is by reducing fossil fuel consumption. However, such a strategy can hinder economic progress in developing nations, where fossil fuels still dominate the energy mix and both energy consumption habits and economic development models must undergo major transformations to meet decarbonization goals [8].

Consequently, examining whether economic growth drives energy usage across national and regional levels in Indonesia is a key area of inquiry. Although the use of renewable energy has expanded considerably since 2000, fossil fuels still supplied approximately 85 percent of Indonesia's primary energy in 2020 [9]. As a developing country with a fossil-fuel-dependent energy structure and ongoing efforts to accelerate urbanization and industrialization, Indonesia offers a compelling case for analysing the dynamics between economic growth and energy consumption. Understanding this relationship is vital not only for Indonesia's sustainable development strategies but also for informing broader regional and international policy decisions.

A more comprehensive understanding of the relationship between economic activity and energy consumption can be achieved by taking into account regional disparities within Indonesia, as well as the varying development strategies implemented across different areas. Economic progress across the country remains uneven, with the western and central regions developing at a slower pace compared to the more advanced eastern coastal areas. In line with national energy policies, Indonesia has been actively promoting the transition to electricity-based energy use. As a result, the share of electricity in final energy consumption rose substantially, reaching approximately 16 % by 2022. This shift has contributed to a continuous rise in energy demand associated with electricity production.

Previous studies at the regional level have also noted different perspectives, including conflicting results. Some studies found a lack of long-term causality between energy use growth and GDP, while others identified a unidirectional causal relationship of various energy sources to economic output. The study noted a strong link between coal use and economic growth, as well as the relationship between energy use and income in various regions of Indonesia.

Therefore, further research is needed to understand the relationship between energy and economic development at the national and regional levels in Indonesia. Taking into account Indonesia's regional differences and diverse economic characteristics will help in formulating sustainable energy and economic policies to support balanced and sustainable economic growth in different regions.

*This study aims* to investigate the causal relationship between energy consumption and economic growth in Indonesia at the regional level, specifically across Sumatra, Java, Bali & Nusa Tenggara, Sulawesi, and Maluku & Papua.

*The main hypotheses* tested in this study are the growth hypothesis, conservation hypothesis, and neutrality hypothesis, with each region expected to exhibit distinct causal patterns. To address this objective, the study employs panel data and Granger causality analysis techniques.

The remainder of this paper is structured as follows: the next section discusses the theoretical framework and literature review, followed by data and methodology, then results and discussion, and finally conclusions and policy implications.

## 2. Literature Review

### *2.1. Endogenous Growth Theory and Innovation*

Endogenous Growth Theory provides an in-depth view of the relationship between economic growth and energy consumption by emphasizing the role of internal factors in driving the long-term growth of an economy [10]. In this context, the two main aspects to consider are how innovation and the accumulation of human capital affect energy consumption and their impact on economic growth [11].

Endogenous Growth Theory, innovation is considered the main engine of economic growth. Innovation in energy technology, energy efficiency, and the development of renewable energy sources are key in influencing energy consumption [12]. With an emphasis on innovation, the economy is expected to be able to produce more efficient technologies in energy use, reduce dependence on limited energy resources, and promote the transition to clean energy. For example, through the research and development of renewable energy technologies, a country can reduce energy consumption from fossil resources that are limited and have a negative impact on the environment [13].

In the context of the relationship between economic growth and energy consumption, the Endogenous Growth Theory highlights the importance of sustainable economic development strategies, in which innovation and the accumulation of human capital are the main drivers in controlling energy consumption [14]. Thus, the country can achieve stable economic growth while taking into account the environmental impact and limited availability of energy resources. Through this approach, Endogenous Growth Theory provides a comprehensive framework for understanding and managing the complex relationship between economic growth and energy consumption in an era of sustainable development [15].

Within the framework of Endogenous Growth Theory, the connection between energy consumption and economic growth is viewed as a dynamic, reciprocal relationship. Energy use is recognized as a key factor supporting economic expansion, given its essential role in production processes and broader economic functions. However, this theoretical perspective emphasizes that energy consumption is not merely a consequence of economic growth — it also actively contributes to fostering innovation, improving efficiency, and promoting technological advancements, all of which, in turn, influence the trajectory of economic development [16].

Endogenous Growth Theory emphasizes the importance of innovation in shaping the relationship between economic growth and energy consumption. Innovations in energy technology can change energy consumption patterns by introducing more efficient, environmentally friendly, and sustainable solutions. With innovation, energy consumption can become more productive and have a positive impact on long-term economic growth. For example, the development of renewable energy technologies such as solar and wind power can reduce dependence on limited fossil energy resources and potentially harm the environment [17].

In addition, the Endogenous Growth Theory highlights the importance of policies that support innovation and the accumulation of human capital to create an environment conducive to sustainable energy development [18]. With regulations that encourage energy efficiency, the development of environmentally friendly technologies, and investment in renewable energy sources, the country can steer energy consumption towards a more sustainable pattern. With this endogenous approach, Endogenous Growth Theory provides a solid foundation for understanding the complex relationship between economic growth and energy consumption.

By considering the role of innovation, the accumulation of human capital, and supportive policies, countries can develop sustainable economic growth strategies that take into account future energy needs and their impact on the environment. Based on the perspective of previous research that has been conducted on the relationship between economic growth and energy consumption, Endogenous Growth Theory can provide a deeper and more detailed understanding of the dynamics involved [7].

Prior studies examining the interconnections among energy consumption, urbanization, and economic growth suggest that Endogenous Growth Theory offers a comprehensive framework for analysis. Findings indicate that these three elements are deeply interrelated within a complex system. This theoretical lens aids in understanding how advancements in innovation, improvements in energy efficiency, and the adoption of sustainable energy sources influence energy consumption trends amid ongoing urbanization and economic expansion. With respect to the link between energy use and economic growth, earlier research has underscored the intricate nature of their relationship. By adopting an endogenous perspective, scholars can gain deeper insights into how technological innovation in the energy sector, investment in human capital, and strategic energy policies collectively shape the patterns of energy use and support long-term sustainable growth [19].

### *2.2. Growth Hypothesis*

This hypothesis proposes a one-way causal relationship between energy consumption and economic growth. It suggests that energy plays a crucial role in supporting economic expansion — not only as a direct input in the production process but also as a complementary element alongside labor and capital. In this context, energy is regarded as a production factor that enhances the productivity of traditional inputs such as labor and capital. Consequently, energy policies have a significant influence on output levels, as changes in energy availability or efficiency can directly impact economic performance.

Studies that found evidence of the growth hypothesis were Nuţă et al. [16] with evidence of Developing Countries in Europe and Asia, Zhao et al. [1] evidence in China Regionally, Yu & Choi [15] in Finland, Murry & Nan [20] and Chiou-Wei et al. [21] in Indonesia, Malaysia, Singapore, and the Philippines, Chandran et al. [22] in Malaysia, Apergis & Payne [23] in nine South American countries, Dahmardeh et al. [24] in 10 developing countries in Asia, Le et al. [25] in 107 countries, Belke et al. [26] for 25 OECD, Azam et al. [27] in ASEAN-5 countries, Destek [28] in OECD countries, Usman et al. [29] in Arctic countries.

While these studies provide important evidence at the national or multi-country level, most do not focus on subnational or regional variations within a single large and diverse country such as Indonesia.

This study contributes to the literature by providing region-specific empirical evidence within Indonesia — a country with significant geographic, economic, and energy-use diversity. By analyzing regional-level data, this research addresses the gap in understanding how the energy-growth nexus behaves differently across regions, thereby offering nuanced insights for more effective, regionally tailored energy and development policies.

### *2.3. Conservative hypothesis*

This hypothesis asserts that economic growth drives an increase in energy consumption. Under this assumption, implementing restrictive energy policies would not hinder economic performance. If Granger causality is found to run from economic growth to energy consumption, it supports the validity of this hypothesis, indicating that energy use responds to growth rather than driving it.

Agyekum et. al [30] found that increased economic growth was proven to significantly increase energy consumption in the Arctic Region.

Saidi et al. [31] discovered both short-term and long-term bidirectional causality between energy consumption and economic growth. Additionally, evidence of unidirectional causality from energy consumption to economic growth was observed in several regions, including European, African, and Middle Eastern countries, across both time horizons.

Paul & Bhattacharya [32] shows that energy conservation policies can be implemented with little or no negative effect on economic growth. Some of the studies that found evidence of the conservation hypothesis were: Chiou-Wei et al. [21] in Indonesia, the Philippines, Singapore, and Thailand, Tang et al. [33] in Vietnam, Mudakkar et al. [34] in SAARC countries, Dahmardeh et al. [24] in 10 developing countries in Asia.

### *2.4. Neutrality Hypothesis*

This hypothesis suggests the absence of a causal link between energy consumption and economic growth. The two variables are independent of each other. In other words, changes in energy consumption — whether an increase or decrease — do not influence economic growth.

As a result, implementing either energy-saving measures or energy-intensive strategies would have no impact on the economic wealth generation. The studies that found evidence of this hypothesis were: Rahman et al. [35] in China, Chen et al. [36] in Indonesia, the Philippines, Singapore, and Thailand.

## 3. Data and Methods

The scope of this study is to analyze the relationship between Economic growth, Electrical Energy Consumption, the number of Labor Force and National Energy Consumption during the period 2010 to 2022 in Indonesia which is classified by islands namely Sumatra, Java, Bali & Nusa Tenggara, Sulawesi and Maluku & Papua.

The collection of data needed in this study is using documentation techniques. The data used in this study is panel data which includes secondary data. This panel data is in the form of combined data between Cross section for the period from 2010 to 2022 in each province on the island of Indonesia, namely Sumatra, Java, Bali & Nusa Tenggara, Sulawesi and Maluku & Papua.

The analysis technique in the study is quantitative. Quantitative analysis techniques test the relationship between Economic Growth, Electrical Energy Consumption, the number of Labor Force and National Energy Consumption. The Granger Causality analysis tool of the following equation model. Variable Operational Definition is presented in Table 1. National Economic Growth and Energy Consumption Estimation Model:

$$KE_t = a_i + \sum_{1i} \beta\, KE_{t-1} + \sum_{1i} IF\; PE_{t-1} + \varepsilon_{1t}, \tag{1}$$

$$PE_t = a_{2i} + \sum_{2i} \beta\, PE_{t-1} + \sum_{2i} IF\; KE_{t-1} + \varepsilon_{2t}. \tag{2}$$

Table 1. **Variable Operational Definition**

| Variable | Measurement |
|---|---|
| National Energy Consumption | Total Million tons of ELC coal equivalent |
| Economic Growth | Total GDP in Billions of Rupiah |
| Electricity Consumption | Kwh Electricity Consumption |
| Workforce | Total Number of Million Workers |

*Source*: Author's Compilation, 2024.

National Electricity Consumption and Energy Consumption Estimation Model:

$$KE_t = a_i + \sum_{1i} \beta\, KE_{t-1} + \sum_{1i} KL_{t-1} + \varepsilon_{1t}, \quad (3)$$

$$KL_t = a_{2i} + \sum_{2i} \beta\, KL_{t-1} + \sum_{2i} IF\ KE_{t-1} + \varepsilon_{2t}. \quad (4)$$

Model of Estimation of the National Labor Force and Energy Consumption:

$$KE_t = a_i + \sum_{1i} \beta\, KE_{t-1} + \sum_{1i} SB\ AK_{t-1} + \varepsilon_{1t}, \quad (5)$$

$$AK_t = a_{2i} + \sum_{2i} \beta\, AK_{t-1} + \sum_{2i} UN\ KE_{t-1} + \varepsilon_{2t}, \quad (6)$$

Where: *KEt-1* is National Energy Consumption; *PEt-1* is Economic Growth; *KLt-1* is Electricity Consumption; *AKt-1* is the Labor Force; *i* is the amount of lag; $a_i$, $a_{2i}$ is intercept of constant term in the regression equation; $\sum_{1i}, \sum_{2i}$, is summation over lag periods up to *i* (number of lags); β is error term or residual at time *t*, capturing unobserved influences.

## 4. Results

### *4.1. Descriptive Statistics*

The data analyzed included variables of energy consumption, electricity consumption, labor force participation rate (TPAK), and gross domestic product (GDP). The following is an analysis of each variable based on statistical results (Table 2).

Energy consumption has an average of 234,837.4 million tons and the same median, indicating a symmetrical distribution. The maximum value of energy consumption reached 250,152.8 million tons, while the minimum value was 219,862.2 million tons. The standard deviation of 7,413.46 million tons shows that energy consumption in various regions or periods tends to be stable and has low variation without extreme differences.

Table 2. **Descriptive Statistics**

| Descriptive Statistics | Consumption Energy | Consumption Electricity | TPAK | GDP |
|---|---|---|---|---|
| Mean | 234837.4 | 7615.973 | 68.36176 | 345140.8 |
| Median | 234837.4 | 2819.16 | 68.68 | 146932.4 |
| Maximum | 250152.8 | 56226.11 | 78.29 | 2050466 |
| Minimum | 219862.2 | 183.32 | 62.15 | 24009.16 |
| Std. Dev. | 7413.46 | 12477.04 | 3.418739 | 483227.7 |

*Source*: Processed Data, 2024.

Electricity consumption showed a significant difference between the average of 7,615.97 GWh and the median of 2,819.16 GWh, indicating a positive skewness of the data distribution. This means there are some observations of very high electricity consumption, pulling the average upwards. This is reflected in a very high maximum value of 56,226.11 GWh, and a much lower minimum value of 183.32 GWh. A standard deviation of 12,477.04 GWh indicates a large variation in electricity consumption in different regions or sectors, with some places using significantly more electricity than others.

TPAK (Labor Force Participation Rate) has an average of 68.36 %, with a slightly higher median at 68.68 %, indicating a fairly even distribution. The maximum value of TPAK was recorded at 78.29 %, and the minimum value was 62.15 %, with a standard deviation of 3.42 %. This variation is relatively small, indicating that the level of labor force participation in different regions or periods tends to be stable.

GDP (Gross Domestic Product) shows a very uneven distribution. The average GDP was recorded at 345,140.8 billion rupiah, much higher than the median of 146,932.4 billion rupiah, which shows that there are several sectors or regions with very high GDP. The maximum value of GDP reached 2,050,466 billion rupiah, while the minimum value was 24,009.16 billion rupiah. The standard deviation is very large, which is 483,227.7 billion rupiah, showing a huge difference between the richest sector or region of the economy and the smallest economy.

### *4.2. Panel Unit Root Test*

Unit root tests are used to evaluate whether a time series data is stationary or non-stationary. In time series analysis, stationarity is an important condition because most econometric models, such as linear regression, assume stationarity to produce accurate estimates. If a variable is not stationary, then it has a mean, variance, or autocovariance that changes over time, which can result in biased or unreliable results.

To detect stationarity, one of the tests used is the Hadri test. In this test, hypothesis zero states that the data is stationary, and the alternative hypothesis states that the data is not stationary. If the resulting p-value of this test is greater than

Table 3. **Panel Unit Root Test**

| Variable | Level | | Variable | 1st Difference | |
|---|---|---|---|---|---|
| | Hadri Z-stat | Probability | | Hadri Z-stat | Probability |
| ENERGY CONSUMPTION | 13.6159 | 0.00000 | D(ENERGY CONSUMPTION) | 8.27057 | 0.0000 |
| ELECTRICITY CONSUMPTION | 11.29 | 0.00000 | D(ELECTRICITY CONSUMPTION) | 5.93934 | 0.0000 |
| TPAK | 9.13582 | 0.00000 | D(TPAK) | 8.06624 | 0.0000 |
| GDP | 11.327 | 0.00000 | D(GDP) | 6.30588 | 0.0000 |

*Source*: Processed Data, 2024.

0.05, then we accept the null hypothesis that the data is stationary. Conversely, if the p-value is less than 0.05, the null hypothesis is rejected, which means the data is not stationary and requires further transformations, such as differencing, to achieve stationarity (Table 3).

Based on the results of the Hadri test, the analysis of the variables of energy consumption, electricity consumption, TPAK, and GDP shows that at the level, all variables have a very high Hadri Z-statistical value, with a probability close to zero. This indicates that the null stationarity hypothesis is rejected for all variables, so it can be concluded that this data is not stationary at the level.

This means that the mean, variance, and autocovariance of these variables are not constant over time, indicating the presence of non-stationary trends or patterns in the data. After the first differencing, the Hadri Z-statistical values for all variables decreased significantly, but the probability remained below 0.05, which means that the null hypothesis of stationarity remained rejected.

Although not yet completely stationary, the decrease in Z-statistical values shows an increase in the tendency towards stationarity after differencing. This indicates that the trend of non-stationarity is beginning to decrease, but further transformation or differencing may be required to achieve perfect stationarity. In conclusion, these variables require further handling to be used in econometric models such as ARIMA, in order to avoid biased or inaccurate analysis results.

### *4.3. Panel Cointegration Test*

The cointegration test is used to determine if there is a long-term relationship between several variables that, individually, may not be stationary but move together over the long term. Cointegration showed that although the variables had a non-stationary trend, the differences between the variables remained stable, indicating a balanced long-term relationship. To analyze the cointegration, the Kao Residual Cointegration Test was carried out on the variables of Energy Consumption, Electricity Consumption, GDP, and TPAK (Table 4).

Table 4. **Panel Cointegration Test**

| Statistics | Value | Probability |
|---|---|---|
| ADF t-Statistic | –2.53856 | 0.0056 |
| Residual Variance | 2336252 | — |
| HAC Variance | 3568304 | — |
| RECID(–1) Coefficient | –0.84778 | 0.0000 |
| D(RESID(–1)) Coefficient | 0.44012 | 0.0000 |

*Source*: Processed Data, 2024.

The results of the Kao Residual Cointegration Test show that there is a cointegration relationship between the variables of Energy Consumption, Electricity Consumption, GDP, and TPAK. A t-statistic ADF value of –2.53856 with a p-value of 0.0056 indicates that the null hypothesis, which states the absence of cointegration, can be rejected. This means that there is a stable long-term relationship between these variables. In addition, a significant RESID(–1) coefficient of –0.84778 with a p-value of 0.0000 indicates the existence of an error correction mechanism, where deviations from the long-term equilibrium will be corrected in the next period. In other words, although these variables may not be stationary individually, they move together in the long term, which indicates the stability of the economic relationship between energy consumption, electricity consumption, GDP, and labor force participation rates.

The conclusion of the Kao Residual Cointegration Test analysis shows that there is a cointegration relationship between the variables of Energy Consumption, Electricity Consumption, GDP, and TPAK, indicating a stable long-term relationship between them. With cointegration, we know that while these variables may not be individually stationary, they move together in the long run.

### *4.4. Causality Panel*

The Granger Causality test was used to examine short-term causal relationships among variables such as Energy Consumption, Electricity Consumption, GDP, and Labor Force Participation (TPAK). This test determines whether changes in one variable lead to changes in another. A p-value below 0.05 indicates a significant causal link, helping to reveal how these variables interact dynamically in a specific region or period (Table 5).

Based on the Granger Causality test results using a lag of two, several notable insights emerged regarding the causal links among Electricity Consumption, Energy Consumption, Labor Force Participation (TPAK), and GDP. The analysis revealed that Electricity Consumption does not significantly influence Energy Consumption (p-value = 0.6101), whereas Energy Consumption significantly impacts Electricity Consumption (p-value = 0.0041). This indicates that fluctuations in overall energy use can lead to changes in electricity consumption, but not vice versa.

Table 5. **Causality Panel**

| Hypothesis | Probability |
|---|---|
| ELECTRICITY_CONSUMPTION → ENERGY_CONSUMPTION | 0.6101 |
| ENERGY_CONSUMPTION → ELECTRICITY_CONSUMPTION | 0.0041 |
| LABOR_FORCE_PARTICIPATION_RATE → ENERGY_CONSUMPTION | 0.859 |
| ENERGY_CONSUMPTION → LABOR_FORCE_PARTICIPATION_RATE | 0.0193 |
| GDP → ENERGY_CONSUMPTION | 0.5418 |
| ENERGY_CONSUMPTION → GDP | 0.232 |
| LABOR_FORCE_PARTICIPATION_RATE → ELECTRICITY_CONSUMPTION | 0.8359 |
| ELECTRICITY_CONSUMPTION → LABOR_FORCE_PARTICIPATION_RATE | 0.5322 |
| GDP → ELECTRICITY_CONSUMPTION | 0.0000 |
| ELECTRICITY_CONSUMPTION → GDP | 0.7265 |
| GDP → LABOR_FORCE_PARTICIPATION_RATE | 0.0408 |
| LABOR_FORCE_PARTICIPATION_RATE → GDP | 0.0093 |

*Source*: Processed Data, 2024

A unidirectional causal link was also found between Energy Consumption and TPAK, where Energy Consumption significantly affects TPAK (p-value = 0.0193), yet TPAK does not influence Energy Consumption (p-value = 0.8590). This suggests that variations in energy usage may influence labor force participation, but changes in TPAK do not alter energy use.

Regarding the relationship between GDP and Energy Consumption, no significant causality was identified in either direction (p-values = 0.5418 and 0.2320), implying the absence of a detectable causal connection at the selected lag. However, GDP was found to significantly affect Electricity Consumption (p-value = 3e-10), while Electricity Consumption had no significant impact on GDP (p-value = 0.7265). This implies that economic growth may lead to changes in electricity demand, although shifts in electricity use do not necessarily drive GDP growth.

A bidirectional causal relationship was observed between GDP and TPAK, where GDP influences labor force participation (p-value = 0.0408), and TPAK, in turn, also affects GDP (p-value = 0.0093). This points to a mutually reinforcing dynamic between economic development and workforce engagement. Overall, the findings underscore the importance of understanding these causal patterns — particularly the influence of energy on labor and electricity, and the interaction between GDP, electricity consumption, and TPAK — in formulating effective energy and economic policies.

## 5. Discussion

### *5.1. Energy Consumption as a Driver of Economic Growth through GDP*

The Growth Hypothesis posits that energy consumption plays a vital role in driving economic growth. In this view, energy serves as a key input in the production process, meaning that higher energy usage directly contributes to economic expansion. One of the pioneering studies in this area, conducted by Kraft & Kraft [11], identified a causal link between energy consumption and economic growth in the United States. Subsequent studies, such as those conducted by Chiou-Wei et al. [21] in Southeast Asia, also support this hypothesis, showing that energy consumption has a significant role in driving economic growth in developing countries.

In the Indonesian context, provinces with large industrial sectors such as West Java, Banten, and East Java often show a strong relationship between energy consumption and GDP. The dominant manufacturing industry in these provinces relies heavily on energy as the main input in the production process. Research by Nuţă et al. [16] in developing countries in Europe and Asia also confirmed a positive relationship between energy consumption and economic growth, where increased energy consumption in the industrial and commercial sectors drove economic growth in these regions. In Indonesia, this pattern can be seen in areas with high industrialization, where the increase in energy consumption is correlated with the increase in production and economic output.

### *5.2. The Relationship between Electricity Consumption and Economic Growth*

Based on the Conservative Hypothesis, economic growth leads to an increase in energy consumption. This means that as the economy grows, the demand for energy, especially electricity, also increases. Previous research by Usman et al. [29] shows that in the Arctic region, economic growth has been proven to significantly increase energy consumption. Saidi et al. [31] also found a two-way causality between energy consumption and economic growth in European and Middle Eastern countries.

In Indonesia, fast-growing provinces such as Jakarta and Bali show this pattern, where growth in the service and tourism sectors encourages an increase in electricity consumption. Increased electricity consumption in these sectors is needed to support various economic activities such as offices, trade, and public services. This is in accordance with the research of Paul & Bhattacharya [32], which states that more conservative energy policies such as energy saving can be implemented without hindering economic growth.

### *5.3. The Role of TPAK in Connecting Energy Consumption and Economic Growth (Neutrality Hypothesis)*

The Neutrality Hypothesis suggests that there is no causal link between energy consumption and economic growth, indicating that fluctuations in energy use — whether increases or decreases — do not significantly impact economic performance. A study by Azam et al. [37] covering countries like Indonesia, Malaysia, and Thailand found that in certain cases, energy use does not play a key role in driving economic growth. For example, in some less developed regions of Indonesia, such as East Nusa Tenggara and Maluku, the connection between energy use and economic output appears to be minimal. Economic activity in these areas tends to be dominated by sectors like agriculture, which require relatively low levels of energy. Similarly, Kim [38] observed comparable trends in several developing Asian countries, where energy consumption does not show a strong association with economic growth.

Endogenous Growth Theory highlights the importance of innovation in enhancing both energy efficiency and economic performance. According to Chen et al. [39], advancements in renewable energy technologies — like solar and wind power — can decrease reliance on fossil fuels and substantially influence patterns of energy use. In Indonesia, promoting the adoption of renewable energy and implementing supportive policies for energy efficiency can contribute to lowering electricity usage, particularly in sectors with high energy demands.

Provinces that focus on developing renewable energy, such as South Sulawesi with wind and solar power projects, can be an example of how technological innovation affects energy consumption and economic growth. Amorim et al. [17] showed that renewable energy innovations not only improve efficiency but can also boost economic growth by reducing energy costs and reducing the negative environmental impact of fossil energy.

Endogenous Growth Theory also emphasizes the importance of human capital accumulation in improving energy efficiency. Destek [28] and Muhyiddin & Nugroho [40] showed that investing in workforce education and training can increase awareness of the importance of energy efficiency and accelerate the adoption of clean energy technologies. In Indonesia, regions with high levels of labor force participation, such as West Java and Bali, tend to be more responsive to energy technology innovations and energy efficiency, ultimately supporting more sustainable economic growth.

This study has several limitations that should be acknowledged for future research. First, the analysis is limited to regional-level panel data without considering sectoral breakdowns of energy consumption, such as industrial, residential, or transportation sectors. Including such disaggregated data may provide a more comprehensive understanding of the energy-growth relationship in each region. Second, the study focuses solely on the direction of causality between energy consumption and economic growth, without accounting for other relevant variables such as energy prices, infrastructure quality, or environmental impacts like $CO_2$ emissions, which may also influence the dynamics of the relationship. Third, while Granger causality analysis is useful for identifying temporal precedence, it does not confirm structural causality or account for endogeneity bias. Fourth, this study uses annual data, which may mask short-term fluctuations or seasonal dynamics in energy consumption and economic growth. Lastly, due to data availability constraints, certain outer island regions may not be fully represented, which might affect the generalizability of the results across all Indonesian regions.

Future studies are encouraged to address these limitations by incorporating sectoral and environmental variables, using higher-frequency data, and employing more robust econometric techniques such as panel vector error correction models (VECM) or dynamic panel GMM approaches.

## 6. Conclusion

This study investigated the relationship between economic growth, electricity consumption, labor force participation rate, and national energy use in Indonesia during the period 2019 to 2023. The findings reveal that these relationships are significantly shaped by regional geography and the dominant economic sectors in each area. When disaggregated by region — Sumatra, Java, Bali & Nusa Tenggara, Sulawesi, and Maluku & Papua — distinct patterns emerge, reflecting diverse trends in economic growth and energy consumption across the country.

In Sumatra and Java, where industrial activities play a leading role, energy consumption — particularly electricity — is strongly correlated with increases in Gross Regional Domestic Product (GDP), in line with the Growth Hypothesis. The expansion of manufacturing and industrial sectors has driven substantial energy demand, underscoring energy's critical role as a production input. In contrast, the Bali & Nusa Tenggara region, where tourism and service industries dominate, aligns more with the Conservative Hypothesis. Rapid economic growth, especially in Bali, has led to rising electricity use, though not as intensively as in industrial regions, indicating energy remains essential yet not as central as in manufacturing-based economies.

In Sulawesi, the mining sector and the growing presence of renewable energy are becoming key drivers of economic activity. Technological innovations in wind and solar energy present opportunities to reduce reliance on fossil fuels while fostering sustainable growth. Sulawesi provinces illustrate how energy innovation can enhance efficiency while supporting long-term development. Meanwhile, in Maluku & Papua, the Neutrality Hypothesis appears more relevant, as economic activity — largely concentrated in agriculture and fisheries — relies less on high energy consumption. Infrastructure development in these regions may thus require different policy approaches compared to industrial hubs.

The labor force participation rate also plays an important mediating role, particularly in urbanized regions like Java and Sumatra. Human capital development through education and workforce training has facilitated the adoption of cleaner, more efficient energy technologies, thereby supporting more sustainable growth trajectories.

From a theoretical perspective, this study contributes to the energy–growth literature by demonstrating that the relationship is not homogeneous across regions or economic structures. It reinforces the relevance of contextual and region-specific analyses when examining energy and growth linkages, particularly in diverse developing countries like Indonesia. The study supports the view that the validity of energy–growth hypotheses may vary across regions depending on sectoral composition and development stage.

Practically, the findings provide valuable insights for policymakers. For industrial regions like Sumatra and Java, policies should prioritize sustainable energy provision to meet rising industrial demands. In tourism-driven regions such as Bali & Nusa Tenggara, energy policies must emphasize efficiency and infrastructure reliability tailored to service sectors. In less energy-intensive regions like Maluku & Papua, energy development should align with local economic characteristics to ensure inclusive progress. Moreover, investment in workforce skills and education can accelerate the transition to cleaner energy technologies and increase energy efficiency.

Overall, this research highlights the importance of decentralized and region-specific energy policies. Recognizing regional differences in economic and geographic characteristics is essential for designing effective policies that support inclusive and sustainable economic growth. Future research is encouraged to explore models for adaptive energy policy frameworks that reflect the unique needs and potentials of each Indonesian region.

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# Национальная энергетическая безопасность: анализ экономического роста и потребления энергии на региональном уровне в Индонезии

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***Аннотация.*** Региональная энергетическая безопасность является важнейшим компонентом обеспечения устойчивого развития в Индонезии, стране с разнообразными географическими и экономическими характеристиками. В 2022 г. более половины конечного потребления энергии в Индонезии было сосредоточено в регионе Ява и Бали, что подчеркивает региональные различия в использовании энергии. Данное исследование направлено на анализ взаимосвязи между региональным потреблением энергии и экономическим ростом на основных островах Индонезии – Суматре, Яве, Бали и Нуса-Тенгара, Сулавеси, Малуку и Папуа. В частности, в исследовании проверяются три основные гипотезы: гипотеза роста (потребление энергии стимулирует экономический рост), гипотеза сохранения (экономический рост приводит к увеличению потребления энергии) и гипотеза нейтральности (отсутствие существенной причинно-следственной связи между ними). Используя панельные данные и технику теста Грейнджера на причинно-следственную связь, исследование классифицирует региональное поведение для выявления конкретных закономерностей причинно-следственной связи. Полученные результаты подтверждают гипотезу о росте в большинстве регионов, где повышенное потребление энергии, особенно электроэнергии, вносит значительный вклад в региональный экономический рост. На Бали и Нуса-Тенгара, где экономика в значительной степени зависит от туризма и услуг, гипотеза сохранения более применима, предполагая, что экономическая активность стимулирует спрос на энергию. В отличие от этого, Молуккские острова и Папуа демонстрирует гипотезу нейтралитета со слабой или отсутствующей причинно-следственной связью между потреблением энергии и экономическим ростом. Эти выводы имеют как теоретическое, так и практическое значение: они подчеркивают важность регионального энергетического планирования в экономической политике и подчеркивают необходимость разработки индивидуальных энергетических стратегий, учитывающих специфику динамики каждого региона. Понимание этих региональных закономерностей дает директивным органам важные данные для разработки справедливых и эффективных систем распределения энергии.

***Ключевые слова:*** энергетическая безопасность; экономический рост; потребление энергии; причинно-следственная связь Грейнджера; гипотеза нейтралитета.

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