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ECONOMIC GROWTH AND HOUSEHOLD ELECTRICITY CONSUMPTION: THE MEDIATING ROLE OF POPULATION DENSITY AND HOUSEHOLD CUSTOMERS IN JAVA

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Abstract

Household electricity consumption is shaped by demographic and economic dynamics, yet these factors may operate through different mechanisms, particularly in highly urbanized regions. This study examines the effects of population density and economic growth on household electricity consumption in Java, Indonesia, with household electricity customers as a mediating variable. Panel data from six provinces covering 2020–2024 were analyzed using panel data regression with 30 observations. The Random Effect Model (REM) was selected for Model 1, while the Fixed Effect Model (FEM) was selected for Model 2, and mediation was tested using the Sobel test. The results show that population density has a positive and significant effect on household electricity consumption but does not significantly affect household customers. Economic growth has a positive and significant effect on household customers but does not have a significant direct effect on household electricity consumption. Household customers have a positive and significant effect on household electricity consumption and fully mediate the relationship between economic growth and electricity consumption. No significant mediation is found between population density and electricity consumption. These findings indicate that population density primarily increases electricity-use intensity, whereas economic growth influences household electricity consumption through the expansion of the household customer base.

Keywords: economic growth; household electricity consumption; household electricity customers; Java; population density

INTRODUCTION

Electricity is a fundamental necessity in modern society and an essential infrastructure supporting economic activities. Almost all household activities, production, trade, services, and public services depend on the availability of electricity. Urban expansion, industrialization, technological development, and population growth simultaneously increase energy demand within a region. On the other hand, technological advancement can improve energy-use efficiency, indicating that the relationship between regional development and energy consumption is not necessarily linear. This condition demonstrates the importance of considering demographic and economic changes when examining the dynamics of electricity consumption (Tongato, 2026; Inesa Putri, 2026).

This issue has become increasingly important in Indonesia, where population growth continues to increase. Indonesia's population increased from 255.88 million in 2015 to 281.6 million in 2024. This demographic growth has implications for increasing energy demand, particularly in the household sector. The household sector accounts for approximately 42% of total national electricity consumption, making it a strategic sector for energy efficiency and energy planning. Household electricity consumption reflects not only the level of energy utilization but also changes in housing patterns, population density, lifestyles, and the socioeconomic conditions of communities (Jamilatun et al., 2025).

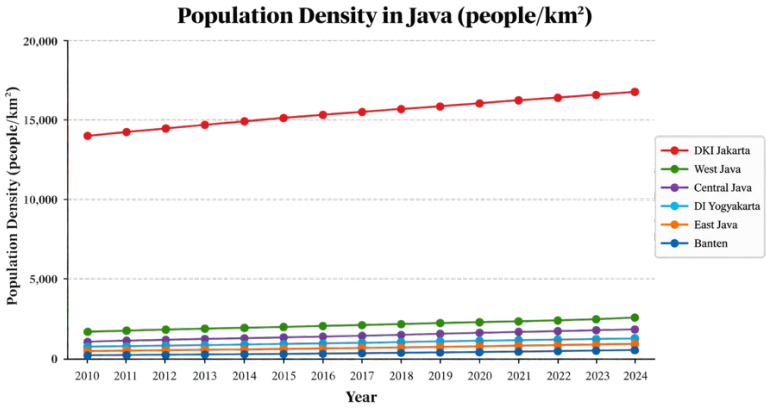

Image 1. Population Density by Province in Java (Inhabitants/km²)
Source: BPS, 2024

One important demographic factor in explaining electricity consumption is population density**.** Population density refers to the number of people occupying a particular land area and is generally expressed as inhabitants per square kilometer (Christiani et al., 2015; Badan Pusat Statistik [BPS], 2024a). Increasing population density means that more people and socioeconomic activities are concentrated within a relatively limited geographical space. Such conditions may increase energy demand through the growth of households, intensified land use, changes in housing characteristics, and increased economic activity. Population growth may also increase the number of household electricity customers served by the national electricity utility, thereby expanding the potential basis of electricity demand (Fevriera & Bima, 2024).

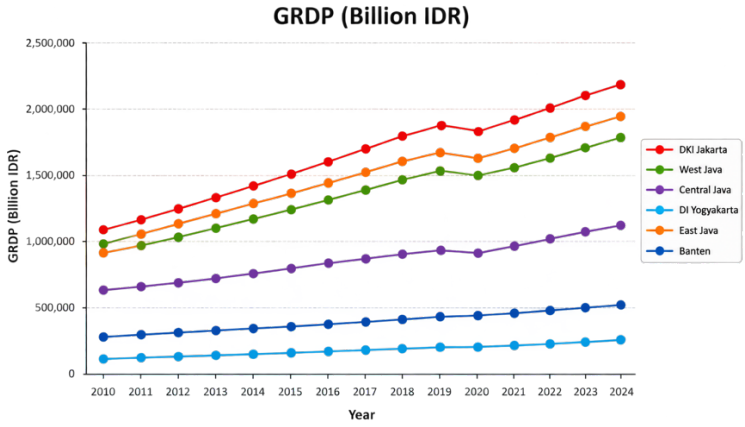

Image 2. Gross Regional Domestic Product (GRDP) by Province in Java (IDR Billion)
Source: BPS, 2024

The issue of population density is particularly significant in Java. Java accommodates more than half of Indonesia's population within a relatively limited geographical area, making it one of the regions with the highest concentrations of population and economic activity. BPS data indicate an increasing trend in population density across several provinces in Java. This condition creates significant implications for infrastructure and energy demand, including household electricity consumption. Several studies have shown that population density can affect electricity consumption through intensified land use, housing characteristics, and the utilization of shared infrastructure (Hardiyanti et al., 2026; Basman et al., 2025). However, the effect of population density on energy consumption may vary depending on regional characteristics and levels of economic development (Zhang et al., 2020; Pablo-Romero & Sánchez-Braza, 2017).

In addition to demographic factors, economic growth is an important factor associated with electricity consumption. Economic growth reflects an increase in a region's capacity to produce goods and services over a particular period, with Gross Regional Domestic Product (GRDP) commonly used as one of its indicators. Increased economic activity may raise household income and purchasing power, thereby encouraging the use of electrical appliances. At the same time, increased production, trade, and service-sector activities require greater electricity consumption. Consequently, economic growth can increase electricity demand through both higher production activities and increased household consumption (Sukirno, 2011; Haryanti & Khristiana, 2024; Burke et al., 2018).

The relationship between economic growth and electricity consumption can also be explained through the Electricity-Growth Nexus**.** Kraft and Kraft (1978) demonstrated a causal relationship between energy consumption and economic growth. Increasing economic activity requires machinery, equipment, and technologies that depend on electricity, while adequate electricity availability can support production activities and economic productivity. Therefore, electricity consumption and economic growth can be structurally interconnected. This relationship is particularly relevant in Java, which serves as both the demographic center and one of the major economic centers of Indonesia.

The relationship between population density and economic growth can be further explained from the perspective of New Economic Geography**.** The concentration of population and economic activities can generate agglomeration economies, economies of scale, labor-market advantages, and knowledge spillovers that increase regional productivity. This process creates circular causality in which large markets attract production activities, increased production creates employment opportunities, employment attracts population, and population growth further expands the market (Krugman, 1991). Under these conditions, greater population and economic concentration may increase electricity demand for both economic activities and household needs.

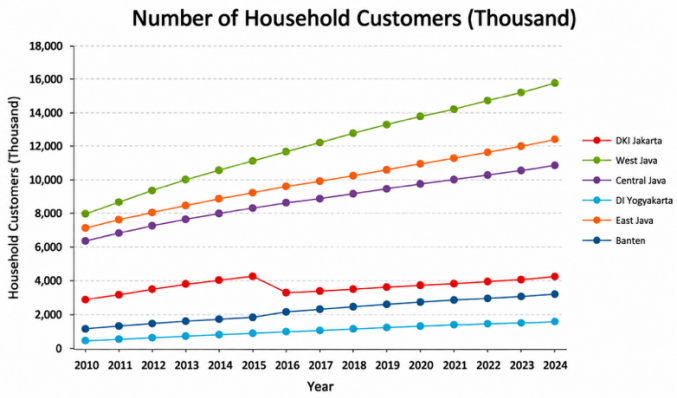

Image 3. Number of Household Electricity Customers by Province in Java (Thousand Customers)
Source: BPS, 2024

Household electricity demand is determined not only by the amount of electricity consumed by individual customers but also by the number of household electricity customers**.** Population growth can increase the number of households and consequently expand the number of electricity customers. An increasing number of customers expands the user base and may therefore increase aggregate household electricity consumption. Thus, the number of household electricity customers can be viewed as an important mechanism linking demographic and economic changes to electricity consumption. Previous research has identified relationships between population growth, electricity customers, and household electricity consumption (Fevriera & Bima, 2024).

The empirical conditions in Java indicate that the number of household electricity customers has generally increased, particularly in areas characterized by high population concentrations and economic activity. At the same time, economic growth varies across provinces, while population density also exhibits different patterns of regional development. The period from 2019 to 2020 further illustrates this variation, as the COVID-19 pandemic caused a significant slowdown in economic activity through declining domestic demand, mobility restrictions, and other economic disruptions (Romadhona et al., 2025). These variations suggest that the relationship between population density, economic growth, the number of household electricity customers, and electricity consumption cannot be adequately understood by examining each factor independently.

Previous studies have provided empirical evidence regarding the relationships among demographic factors, economic growth, and energy consumption, but their findings remain inconsistent. Muzayanah et al. found that population density had a positive and significant effect on electricity and total energy consumption in Indonesia. Similarly, Sari et al. (2025) reported that population density positively affected household energy consumption. In contrast, Fevriera and Bima (2024) found that the effect of population density on electricity consumption could vary when associated with GRDP. Bazán Navarro et al. (2024) identified a long-term relationship between economic growth and electricity consumption, whereas Haryanti et al. (2024) found that the relationship among population growth, electricity consumption, and economic growth did not necessarily produce a significant mediation effect. These divergent findings indicate that the relationships between demographic factors, economic growth, and electricity consumption remain context-dependent.

Based on the existing literature, an important research gap remains. Studies on electricity consumption in Indonesia have largely examined individual relationships between variables or employed conventional regression approaches. Research that simultaneously examines the structural relationships among population density, economic growth, the number of household electricity customers, and household electricity consumption**,** particularly at the provincial level in Java, remains relatively limited. This gap is important because Java has distinctive characteristics, including high population density, concentrated economic activity, increasing numbers of electricity customers, and continuously growing energy requirements. Therefore, an analytical approach that can examine these variables within an integrated structural framework is needed (Sugiawan & Managi, 2016).

The urgency of this study lies in the need to understand the structural mechanisms underlying household electricity consumption in a region experiencing substantial demographic and economic pressures. Such understanding is important not only from an academic perspective but also for energy planning and regional development policy. If increasing electricity consumption is primarily driven by the growth in household customers associated with population density, energy policies need to consider the expansion of basic household electricity requirements. Conversely, if electricity consumption is more strongly associated with economic growth and increasing economic activities, electricity supply planning needs to be aligned with regional economic development.

To address this problem, this study proposes a structural analysis of the relationships among population density, economic growth, the number of household electricity customers, and household electricity consumption**.** Population density is positioned as a demographic factor that may directly affect electricity consumption and indirectly affect it through the number of household customers. Economic growth is positioned as an economic factor that may influence both the number of household customers and electricity consumption through increased economic activity and household purchasing capacity. The number of household electricity customers is subsequently positioned as a factor directly associated with household electricity consumption. This structural framework enables the study to examine not only direct relationships but also the mechanisms through which demographic and economic conditions contribute to household electricity demand.

Accordingly, this study aims to examine the effect of population density on household electricity consumption, examine the effect of population density on the number of household electricity customers, examine the effect of economic growth on the number of household electricity customers, examine the effect of economic growth on household electricity consumption, and examine the effect of the number of household electricity customers on household electricity consumption in Java**.** The study covers six provinces in Java: Banten, Jakarta, West Java, Central Java, the Special Region of Yogyakarta, and East Java.

This study is expected to contribute to the literature on energy consumption by integrating demographic, economic, and electricity-customer factors into a single structural framework. Practically, the findings may provide empirical evidence for policymakers and relevant stakeholders in designing energy-planning policies that account for population density, economic growth, and changes in the number of household electricity customers. Based on this rationale, the study is entitled “Structural Analysis of the Relationships among Population Density, Economic Growth, and Household Electricity Consumption in Java.”

LITERATURE REVIEW

Population Density and Household Electricity Consumption

Population density represents the concentration of population within a particular geographical area and is commonly measured as the number of inhabitants per square kilometer (Christiani et al., 2015; Badan Pusat Statistik [BPS], 2024a). Unlike population size, which captures the absolute number of people, population density reflects the spatial concentration of population and socioeconomic activities. This distinction is important in energy studies because the concentration of households and activities within a limited area may alter patterns of electricity demand through housing characteristics, land-use intensity, infrastructure utilization, and urbanization.

The relationship between population density and electricity consumption can be explained through the increasing demand generated by a greater concentration of households and human activities. As population density increases, the number of households and electricity users may increase, while higher residential and commercial activity can intensify electricity demand. Previous empirical evidence generally supports this relationship. Muzayanah et al. found that population density had a positive and significant effect on electricity and total energy consumption in Indonesia. Similarly, Sari et al. (2025) reported that population density positively affected household energy consumption. These findings suggest that population concentration can create additional pressure on energy demand.

However, the relationship is not necessarily uniform across regions. Fevriera and Bima (2024) found that population density had a negative effect on electricity consumption in their initial model, although the relationship changed when population density interacted with GRDP. Wu and Lin (2022) also found differentiated effects of urbanization and population density on direct and indirect household energy consumption in China. These findings indicate that the effect of population density may depend on the economic and spatial characteristics of a region. High density can increase aggregate electricity demand through population concentration, but it may also generate efficiency gains through shared infrastructure and more compact settlement patterns.

Therefore, the literature suggests two competing mechanisms. The first is an intensification mechanism**,** whereby greater population concentration increases the number of households and activities requiring electricity. The second is an efficiency mechanism, whereby higher density may facilitate more efficient infrastructure and land use. The existence of these competing mechanisms provides a rationale for empirically testing the relationship between population density and household electricity consumption specifically in Java, where population density and economic concentration are exceptionally high.

Population Density and Household Electricity Customers

Population growth and population density are also closely related to the expansion of the household electricity customer base. As population increases and settlements become more concentrated, the number of households requiring electricity services is expected to increase. The number of household electricity customers therefore represents an important demographic channel through which population characteristics may influence aggregate electricity consumption.

Fevriera and Bima (2024) provide empirical evidence that population growth is associated with an increase in household electricity customers. This relationship is conceptually consistent with the basic demand structure of household electricity: an increase in the number of households creates additional potential electricity users. From this perspective, population density does not merely represent demographic pressure but may also reflect the expansion of the electricity customer base.

Nevertheless, the relationship between population density and the number of electricity customers should not be assumed to be proportional. The same population size can produce different numbers of electricity customers depending on household formation, housing structure, urbanization, electricity access, and regional development. Consequently, analyzing the number of household electricity customers separately from total population provides a more specific representation of the mechanism through which demographic conditions may influence electricity demand.

Economic Growth and Household Electricity Customers

Economic growth is commonly represented by changes in regional output, particularly Gross Regional Domestic Product (GRDP). In regional economic analysis, GRDP reflects the value of goods and services produced within a region and provides an important indicator of regional economic performance (Sukirno, 2011). Economic development may influence the number of electricity customers through improvements in household income, housing development, business activity, and access to modern infrastructure.

The relationship can be explained through the expansion of economic capacity. Higher economic activity increases household purchasing power and stimulates the development of residential areas and supporting infrastructure. These processes may increase the number of households that become electricity customers. At the same time, economic development can accelerate urbanization and the expansion of settlements, further increasing the potential electricity customer base.

The New Economic Geography perspective provides an additional explanation for this relationship. Krugman (1991) argues that population and economic activities tend to concentrate geographically because of agglomeration economies, market size, labor availability, and reduced transportation costs. Concentration of economic activity can stimulate employment and population growth, which subsequently expands the local market. This circular process may contribute to the expansion of households and electricity customers in economically developed regions.

However, previous studies have generally focused more heavily on the relationship between economic growth and aggregate energy consumption than on the specific effect of economic growth on the number of household electricity customers. This represents an important distinction because electricity consumption can increase through two different channels: an increase in the number of customers and an increase in electricity use

per customer. Separating these mechanisms can provide a clearer understanding of the structural determinants of household electricity consumption.

Economic Growth and Household Electricity Consumption

The relationship between economic growth and electricity consumption has been widely discussed through the Electricity-Growth Nexus**.** Kraft and Kraft (1978) established an important foundation for examining the causal relationship between energy consumption and economic growth. Economic expansion generally requires greater utilization of machinery, equipment, technology, commercial facilities, and other electricity-dependent activities. Conversely, reliable electricity infrastructure can support productivity and economic activity.

The relationship is also supported by household consumption theory. Keynes (1936) proposed that consumption is related to current income, implying that an increase in income can increase household consumption. Applied to energy demand, higher income may increase the ability of households to purchase and operate electrical appliances. Deaton and Muellbauer's (1980) *Almost Ideal Demand System* further emphasizes the role of income and prices in household expenditure allocation, providing a theoretical basis for examining energy demand as part of household consumption decisions.

Empirical studies generally provide support for a positive relationship between economic growth and electricity consumption. Haryanti and Khristiana (2024) identified a relationship between economic growth and electricity consumption in Indonesia, while Bazán Navarro et al. (2024), using data from Latin America and the Caribbean, found a long-term bidirectional relationship between economic growth and electricity consumption. However, the magnitude and direction of this relationship may differ according to the level of development, economic structure, energy efficiency, and regional characteristics.

This inconsistency indicates that economic growth does not automatically translate into an identical increase in household electricity consumption. Economic expansion accompanied by technological improvements and energy efficiency may reduce electricity intensity, whereas growth driven by energy-intensive activities may increase electricity demand. Therefore, the relationship needs to be examined within a specific regional context rather than assumed to be universal.

Household Electricity Customers and Household Electricity Consumption

The number of household electricity customers is conceptually connected to aggregate household electricity consumption because each additional customer represents a potential additional electricity user. Household electricity consumption can therefore increase through an extensive margin**,** represented by the expansion of the customer base, and an intensive margin**,** represented by higher electricity consumption among existing customers.

This distinction is important because an increase in aggregate electricity consumption does not necessarily indicate that existing households have substantially increased their individual electricity use. Bernard et al. (2024) emphasize the importance of the intensive margin, whereby changes in consumption per customer can contribute to overall electricity demand. At the same time, demographic expansion can increase consumption through the extensive margin by adding new household electricity customers.

The literature therefore supports the importance of incorporating the number of household electricity customers into structural models of electricity consumption. By explicitly including this variable, the analysis can distinguish the role of population and economic conditions in expanding the customer base from their potential direct effects on electricity consumption.

Theoretical Framework

The relationships examined in this study can be understood through several complementary theoretical perspectives. First, the New Economic Geography framework explains how population and economic activities become geographically concentrated through agglomeration economies. Krugman (1991) emphasizes the role of market size, labor concentration, and economic activity in generating cumulative regional development. In a densely populated region such as Java, this concentration can increase both economic activity and demand for supporting infrastructure, including electricity.

Second, the Electricity-Growth Nexus provides a theoretical basis for understanding the relationship between economic growth and electricity consumption. Kraft and Kraft (1978) demonstrate that economic activity and energy consumption may have a causal relationship. Economic growth increases the demand for energy-intensive production and consumption, while electricity availability can support economic productivity.

Third, household consumption and energy-demand theory explains how income and household characteristics influence electricity use. Keynesian consumption theory links consumption to income (Keynes, 1936), while the *Almost Ideal Demand System* developed by Deaton and Muellbauer (1980) provides a framework for understanding household expenditure allocation according to income and prices. In the context of electricity, higher household income can facilitate the acquisition and use of electrical appliances, thereby increasing energy demand.

Fourth, agglomeration economics provides an explanation for why regions with concentrated economic activities may experience higher energy requirements. Marshall (1920) argues that geographic concentration of economic activities can generate external economies through specialized labor markets, localized inputs, and knowledge spillovers. Glaeser (2010) further emphasizes that urban concentration can increase productivity and economic activity. These mechanisms are relevant to Java because population concentration and economic agglomeration occur simultaneously.

Taken together, these theories suggest that household electricity consumption is not determined by a single factor. Instead, it emerges from the interaction between demographic concentration, economic development, the expansion of electricity customers, and household demand. This theoretical integration provides the basis for examining the variables within a single structural framework.

Previous Empirical Studies and Research Gap

Previous empirical studies provide valuable evidence regarding the relationships among population density, economic growth, electricity customers, and electricity consumption. Muzayanah et al. and Sari et al. (2025) provide evidence supporting the positive relationship between population density and energy consumption. Fevriera and Bima (2024), however, demonstrate that the effect of population density can vary according to its interaction with economic conditions. Bazán Navarro et al. (2024) provide evidence of a long-term relationship between economic growth and electricity consumption, while Haryanti et al. (2024) indicate that relationships among population, electricity consumption, and economic growth may not always be statistically significant.

Studies from outside Indonesia also demonstrate that the relationship between urbanization, population density, and energy consumption is context-dependent. Wu and Lin (2022) found differentiated effects of urbanization and population density on direct and indirect household energy consumption in China. Islam et al. (2022) found that urbanization, income, and physical infrastructure significantly influenced household renewable and non-renewable energy consumption in Bangladesh. Nguyen et al. (2024) similarly reported that urbanization increased energy consumption in ASEAN countries, although the effects differed between the short and long run.

Despite these contributions, three important gaps remain. First, previous studies frequently examine population density, economic growth, or urbanization as individual determinants of energy consumption, while fewer studies integrate demographic, economic, and customer-base factors within one structural model. Second, much of the existing Indonesian literature uses national or multi-provincial aggregate data and conventional regression approaches, providing limited evidence regarding the structural mechanism operating within Java as a highly dense and economically concentrated region. Third, the number of household electricity customers has received comparatively less attention as a structural mechanism connecting demographic and economic conditions to aggregate household electricity consumption.

This study addresses these gaps by developing an integrated structural framework consisting of population density, economic growth, the number of household electricity customers, and household electricity consumption. Population density and economic growth are treated as exogenous determinants, while the number of household electricity customers represents an intermediate structural factor associated with household electricity consumption. By examining these relationships simultaneously across the provinces of Java, the study seeks to provide a more comprehensive explanation of the mechanisms underlying regional household electricity demand.

The resulting framework is therefore expected to contribute to the literature in two ways. Theoretically, it integrates demographic, economic, agglomeration, and electricity-demand perspectives to explain household electricity consumption. Empirically, it provides evidence from Java, where population density and economic activity are highly concentrated, thereby extending previous research that has largely examined these relationships separately or at broader geographical scales.

METHOD

Research Design

This study employed a quantitative explanatory research design with an associative approach. The quantitative approach was used because the study relies on numerical secondary data and statistical analysis to

examine the relationships among population density, economic growth, the number of household electricity customers, and household electricity consumption. The associative approach was employed to examine the relationships and effects among the variables included in the structural model (Sugiyono, 2022).

The study was conducted in six provinces on Java Island, Indonesia, namely Banten, Jakarta, West Java, Central Java, the Special Region of Yogyakarta, and East Java. These provinces were selected because Java has a high concentration of population, economic activity, and household electricity customers. The observation period covered 2020–2024, resulting in a province-year panel dataset. The research activities were conducted from May to November 2026.

Population and Sample

The population of this study comprises provincial observations in Indonesia. The sample was determined using purposive sampling based on specific characteristics relevant to the research objectives. The sample consisted of six provinces located on Java Island: Banten, Jakarta, West Java, Central Java, the Special Region of Yogyakarta, and East Java, observed annually from 2020 to 2024.

The selection of Java was based on three considerations. First, the provinces with the largest numbers of household electricity customers are predominantly located on Java. Second, the provinces with the largest and highest population densities in Indonesia are concentrated on Java. Third, the provinces with the largest GRDP values are also predominantly located on Java. These characteristics make Java an appropriate geographical setting for examining the structural relationships between demographic conditions, economic growth, household electricity customers, and household electricity consumption.

Data Sources and Collection

This study used secondary data. Secondary data are data obtained indirectly through sources that have previously collected or published the information required for research (Sugiyono, 2022). The data used in this study consisted of provincial-level information on population density, economic growth, the number of household electricity customers, and household electricity consumption for the 2020–2024 period.

Data collection was conducted using documentation and literature study. Documentation involved collecting and organizing statistical information from relevant government and institutional databases, particularly data published by the Badan Pusat Statistik (BPS) and PT PLN (Persero). Literature study was conducted by reviewing books, academic articles, journals, and previous empirical studies relevant to population density, economic growth, electricity customers, and household electricity consumption. These procedures were used to establish the empirical dataset and strengthen the theoretical basis of the study.

Variable Operationalization

The study consists of three explanatory variables and one dependent variable. Population density (X1) represents the demographic condition of each province and is measured as the number of inhabitants per square kilometer (persons/km²). Economic growth (X2) is represented by provincial Gross Regional Domestic Product (GRDP). The number of household electricity customers (X3) represents the annual number of household electricity customers in each province. Household electricity consumption (Y) represents the annual amount of electricity consumed by household customers and is measured in kilowatt-hours (kWh). All variables are measured using a ratio scale.

Table 1. Operationalization of Research Variables

No.	Variable	Operational Definition and Data Source	Indicator	Measurement	Unit
1	Population Density (X1)	Population density is the number of inhabitants occupying a specific land area within a province. It represents the spatial concentration of population and is measured by the ratio between the total population and the land area of each province. The data were obtained	Population per unit of land area	Total population ÷ land area	Persons/km²

		from the Badan Pusat Statistik (BPS)**.**			
2	Economic Growth (X2)	Economic growth refers to the increase in the real economic output of a province over a given period. It is measured using the annual growth rate of Gross Regional Domestic Product (GRDP) at constant prices (ADHK), which reflects changes in regional economic output without the influence of price changes. The data were obtained from the Badan Pusat Statistik (BPS).	Annual GRDP growth rate at constant prices	[(GRDPt − GRDPt−1) ÷ GRDPt−1] × 100%	Percent (%)
3	Household Electricity Customers (X3)	Household electricity customers refer to the total number of electricity customers classified as household customers in each province during a given year. This variable represents the size of the household electricity customer base. The data were obtained from PT PLN (Persero).	Number of household electricity customers	Annual total number of household electricity customers by province	Customers
4	Household Electricity Consumption (Y)	Household electricity consumption refers to the total amount of electrical energy sold to and consumed by household electricity customers within a province during one year. It represents the aggregate electricity demand of the household sector. The data were obtained from PT PLN (Persero).	Annual household electricity consumption	Total electricity consumed by household customers per year	kWh

Data Analysis

The data were analyzed using statistical techniques to examine the relationships among population density, economic growth, the number of household electricity customers, and household electricity consumption. Descriptive analysis was initially conducted to summarize the characteristics and distribution of the variables across the six provinces and the observation period.

The original research methodology specifies several preliminary statistical tests, including validity, reliability, classical assumption tests, and PLS-SEM analysis. However, because the present study uses secondary provincial data rather than questionnaire responses, questionnaire-based validity and reliability testing are not applicable. Similarly, the Likert-scale scoring procedure described in the original methodology is not relevant to the current dataset.

The structural relationships proposed in the study are represented by the following equations:

$$M_{it} = \alpha_1 + \beta_1 X_{1,it} + \beta_2 X_{2,it} + e_{1,it}$$

$$Y_{it} = \alpha_2 + \beta_3 X_{1,it} + \beta_4 X_{2,it} + \beta_5 M_{it} + e_{2,it}$$

where denotes household electricity consumption in province in year, denotes the number of household electricity customers in province in year, denotes population density, denotes economic growth, denotes the estimated regression coefficient, denotes the intercept, and denotes the error term.

The structural model tests five hypothesized relationships: (1) population density affects household electricity consumption; (2) population density affects the number of household electricity customers; (3) economic growth affects the number of household electricity customers; (4) economic growth affects household electricity consumption; and (5) the number of household electricity customers affects household electricity consumption.

Hypothesis Testing

Hypothesis testing was conducted at a 5% significance level. A relationship was considered statistically significant when the resulting p-value was less than 0.05. A p-value greater than or equal to 0.05 indicated insufficient statistical evidence to support the proposed relationship. The estimated coefficients were also examined to determine the direction of the relationship between the explanatory and dependent variables.

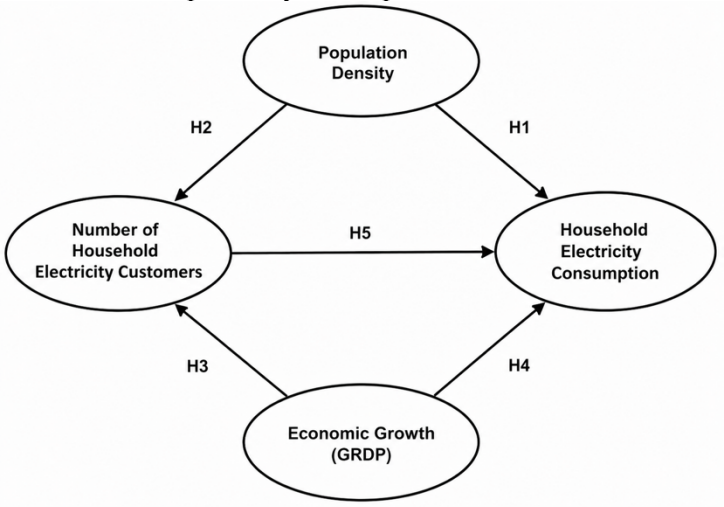

Image 4. Research Model and Hypothesis Framework

The analysis was used to determine whether demographic and economic conditions significantly contribute to the expansion of the household electricity customer base and household electricity consumption in Java.

RESULTS AND DISCUSSION

Descriptive Statistics

The study analyzes panel data from six provinces in Java, Indonesia, covering the period from 2020 to 2024, resulting in 30 observations. The variables examined include Electricity Consumption, Household Customers, Population Density, and Economic Growth. Descriptive statistics are presented in Table 1.

Table 2. Descriptive Statistics of Research Variables (N = 30)

Variable	Mean	Median	Maximum	Minimum	Std. Dev.
Electricity Consumption (Y)	11.912,33	12.365,00	22.700,00	1.580,00	6.577,33
Household Customers (M)	7,71	7,27	15,62	1,03	5,11
Population Density (X_1)	3.642,80	1.209,00	16.165,00	851	5.655,46
Economic Growth (X_2)	3,31	4,94	5,58	−3,39	3,09

Source: EViews 12 output, processed by the authors (2026).

Electricity Consumption has a mean of 11,912.33 GWh, with a median of 12,365.00 GWh. The maximum value is 22,700.00 GWh and the minimum is 1,580.00 GWh, with a standard deviation of 6,577.33 GWh. Household Customers has a mean of 7.71 million customers, a median of 7.27 million, a maximum of 15.62 million, and a minimum of 1.03 million, with a standard deviation of 5.11 million.

Population Density has a mean of 3,642.80 inhabitants/km² and a median of 1,209.00 inhabitants/km². The maximum value is 16,165.00 inhabitants/km², while the minimum is 851.00 inhabitants/km², with a standard deviation of 5,655.46 inhabitants/km². Economic Growth has a mean of 3.31%, a median of 4.94%, a maximum of 5.58%, and a minimum of −3.39%, with a standard deviation of 3.09%.

Panel Data Model Selection

The selection of the appropriate panel data estimation model was conducted using the Chow and Hausman tests. For Model 1, the Chow test produced a probability value of 0.0000, indicating a preference for the Fixed Effect Model over the Common Effect Model. However, the Hausman test produced a probability value of 0.7531. Therefore, the Random Effect Model was selected as the best-fit model for Model 1.

Table 3. Panel Model Selection for Model 1

Test	Statistic	Probability	Selected Model
Chow Test – Cross-section F	1798.7793	0	Fixed Effect
Chow Test – Cross-section Chi-square	180.4711	0	Fixed Effect
Hausman Test – Cross-section random	0.567	0.7531	Random Effect

For Model 2, the Chow test produced probability values of 0.0000 for both the Cross-section F and Cross-section Chi-square statistics. The Hausman test also produced a probability value of 0.0000. Accordingly, the Fixed Effect Model was selected as the best-fit model for Model 2.

Table 4. Panel Model Selection for Model 2

Test	Statistic	Probability	Selected Model
Chow Test – Cross-section F	135.4338	0	Fixed Effect
Chow Test – Cross-section Chi-square	105.1182	0	Fixed Effect
Hausman Test – Cross-section random	108.83	0	Fixed Effect

Regression Results

Model 1: Household Customers

The estimation results for Model 1 using the Random Effect Model are presented in Table 4. Population Density has a coefficient of −0.0003 with a probability value of 0.5068, while Economic Growth has a coefficient of 0.0713 with a probability value of 0.0002. The model has an R-squared value of 0.4100 and an adjusted R-squared value of 0.3663. The F-statistic is 9.3824 with a probability value of 0.0008.

Table 5. Regression Results for Model 1

Variable	Coefficient	Std. Error	t-Statistic	p-value
Constant	8.5217	2.976	2.8635	0.008
Population Density (X_1)	−0.0003	0.0004	−0.6728	0.5068
Economic Growth (X_2)	0.0713	0.0169	4.2153	0.0002
R-squared	0.41	—	—	—
Adjusted R-squared	0.3663	—	—	—
F-statistic	9.3824	—	—	0.0008

The estimated equation for Model 1 is:

$$M\_it = 8.5217 - 0.0003X_1\_it + 0.0713X_2\_it + e\_it$$

Based on the partial test, Population Density does not have a significant effect on Household Customers (p = 0.5068), whereas Economic Growth has a positive and significant effect on Household Customers (p = 0.0002). The simultaneous test indicates that Population Density and Economic Growth jointly have a significant effect on Household Customers (p = 0.0008).

Model 2: Electricity Consumption

The estimation results for Model 2 using the Fixed Effect Model are presented in Table 5. Population Density has a coefficient of 1.3402 with a probability value of 0.0326. Economic Growth has a coefficient of −17.0808 with a probability value of 0.1693, while Household Customers has a coefficient of 2689.6330 with a probability value of 0.0000. The model has an R-squared value of 0.9997 and an adjusted R-squared value of 0.9996. The F-statistic is 8073.616 with a probability value of 0.0000.

Table 6. Regression Results for Model 2

Variable	Coefficient	Std. Error	t-Statistic	p-value
Constant	−13,660.10	2,325.28	−5.8746	0
Population Density (X_1)	1.3402	0.5858	2.2878	0.0326
Economic Growth (X_2)	−17.0808	11.9995	−1.4235	0.1693
Household Customers (M)	2,689.63	107.2722	25.073	0
R-squared	0.9997	—	—	—
Adjusted R-squared	0.9996	—	—	—
F-statistic	8,073.62	—	—	0

The estimated equation for Model 2 is:

$$\mathbf{Y\_it = -13{,}660.10 + 1.3402X_1\_it - 17.0808X_2\_it + 2{,}689.6330M\_it + e\_it}$$

The partial test shows that Population Density has a positive and significant effect on Electricity Consumption (p = 0.0326). Economic Growth does not have a significant effect on Electricity Consumption (p = 0.1693), whereas Household Customers has a positive and significant effect on Electricity Consumption (p = 0.0000). The simultaneous test indicates that Population Density, Economic Growth, and Household Customers jointly have a significant effect on Electricity Consumption (p = 0.0000).

Mediation Results

The Sobel test was conducted to examine the indirect effects of Population Density and Economic Growth on Electricity Consumption through Household Customers. The results are presented in Table 6.

Table 7. Sobel Test Results

Mediation Path	Indirect Effect	Z-statistic	p-value	Result
$X_1 \rightarrow M \rightarrow Y$	−0.7692	−0.6711	0.5022	Not Significant
$X_2 \rightarrow M \rightarrow Y$	191.642	4.157	0	Significant

The indirect effect of Population Density on Electricity Consumption through Household Customers is not significant (Z = −0.6711; p = 0.5022). In contrast, the indirect effect of Economic Growth on Electricity Consumption through Household Customers is significant (Z = 4.1570; p = 0.0000).

The direct effect of Economic Growth on Electricity Consumption is not significant (p = 0.1693), whereas its indirect effect through Household Customers is significant (p = 0.0000). The mediation result therefore indicates a full mediation effect.

Summary of Direct and Indirect Effects

Table 8. summarizes the direct, indirect, and total effects obtained from the path analysis

Relationship	Direct Effect	Indirect Effect	Total Effect	Mediation
$X_1 \rightarrow Y$	1.3402*	−0.7692	0.571	No mediation
$X_2 \rightarrow Y$	−17.0808	191.6420*	174.5612	Full mediation
$X_1 \rightarrow M$	−0.0003	—	−0.0003	—
$X_2 \rightarrow M$	0.0713*	—	0.0713	—
$M \rightarrow Y$	2,689.6330*	—	2,689.*	

*Significant at α = 5%.

The results show that Population Density has a significant direct effect on Electricity Consumption, while its indirect effect through Household Customers is not significant. Economic Growth has a significant indirect effect

on Electricity Consumption through Household Customers, with a total effect of 174.5612. Household Customers has a positive and significant direct effect on Electricity Consumption.

Effect of Population Density on Household Electricity Consumption

The Fixed Effect Model results indicate that Population Density has a positive and significant effect on Household Electricity Consumption, with a coefficient of 1.3402 and a probability value of 0.0326. This finding indicates that higher population density is associated with greater household electricity consumption in Java.

The positive relationship can be understood from the concentration of residential activities and urbanization in densely populated areas. High population density reflects the concentration of settlements and increasingly intensive urban activities. In densely populated areas such as DKI Jakarta, Banten, and metropolitan areas of West Java, limited land availability encourages higher residential density, including vertical housing and other compact settlement patterns. These conditions may increase the intensity of electricity use through greater reliance on household appliances, lighting, cooling systems, communication devices, and other electricity-dependent activities.

Population concentration may also increase household electricity demand through environmental and spatial conditions. Densely built urban areas can experience higher local temperatures, which may increase the use of air-conditioning and other cooling equipment. At the same time, intensive domestic activities in densely populated areas require continuous electricity use for lighting, communication, household appliances, and other daily activities.

An important finding is that Population Density significantly affects Electricity Consumption directly but does not significantly affect Household Customers. The absence of a significant relationship between Population Density and Household Customers suggests that increasing population density does not necessarily result in proportional growth in the number of registered electricity customers. In densely populated urban areas, population growth may be accommodated through rental housing, boarding houses, apartments, or multi-family households that continue to rely on existing electricity connections. Thus, population growth can increase electricity use without necessarily increasing the number of registered customers.

This finding is consistent with Muzayanah et al. (2022) and Sari et al. (2025), which report a positive relationship between population density and household energy consumption in Indonesia. It also supports Wu and Lin (2022), who argue that population concentration in developing regions can generate substantial direct energy demand despite potential infrastructure efficiencies. However, the finding differs from Fevriera and Bima (2024), who reported a negative relationship between population density and energy consumption in East Nusa Tenggara. This difference may reflect variations in regional development, electrification, infrastructure availability, and urbanization between Java and less densely urbanized regions.

Effect of Population Density on Household Customers

The Random Effect Model results show that Population Density does not have a significant effect on Household Customers. The estimated coefficient is −0.000286 with a probability value of 0.5068. Therefore, changes in population density are not statistically associated with changes in the number of registered household electricity customers in Java.

This finding can be associated with the relatively mature electricity infrastructure and high level of electrification in Java. When electricity access has already reached a high level, population density becomes less important as a determinant of new customer formation because most residential areas are already connected to the electricity network. Consequently, additional population concentration does not automatically translate into a proportional increase in new electricity connections.

Housing characteristics may also explain this relationship. In densely populated urban areas, population increases are frequently accommodated through apartments, rental houses, boarding houses, and other forms of high-density housing. Several households or residents may therefore share existing electricity connections rather than registering separate electricity meters. Similarly, multi-generational households can increase the number of residents within an existing household without generating additional registered electricity customers.

The contrasting results between Population Density and the two electricity-related outcomes are particularly relevant. Population Density has a significant direct effect on Electricity Consumption but not on Household Customers. This pattern suggests that population density operates primarily through an intensification of electricity use rather than through an expansion of the customer base**.**

This interpretation is consistent with Diniari et al. and Wu and Lin (2022), who indicate that aggregate demographic changes in highly urbanized areas do not necessarily translate linearly into the expansion of physical utility infrastructure.

Effect of Economic Growth on Household Customers

Economic Growth has a positive and significant effect on Household Customers, with a coefficient of 0.0713 and a probability value of 0.0002. The finding indicates that stronger economic growth is associated with an increase in registered household electricity customers in Java.

The relationship can be explained through the connection between economic development, household purchasing power, and residential expansion. Economic growth, as reflected in regional GDP growth, represents increasing economic activity and improvements in regional income conditions. Higher purchasing power can facilitate household formation, home ownership, residential construction, and the development of new housing units. These processes create additional demand for new electricity connections.

The relationship is particularly relevant during the 2020–2024 observation period. Following the economic contraction associated with the COVID-19 pandemic in 2020, economic recovery during 2021–2024 coincided with the recovery of residential and property-related activities. Expansion of residential areas in suburban and metropolitan corridors can consequently generate new household electricity customers.

Economic improvement may also encourage households that previously relied on shared electricity connections to establish independent electricity connections. Thus, economic growth can contribute not only to physical housing expansion but also to the formalization and expansion of the registered electricity customer base.

The finding strengthens the role of Household Customers as an important transmission mechanism in the research model. The significant relationship between Economic Growth and Household Customers provides the first link through which economic development can subsequently influence household electricity consumption.

This result is consistent with Islam et al. (2022), Bazán Navarro et al. (2024), and Nguyen et al. (2024), which emphasize the role of economic expansion and regional income accumulation in increasing access to and ownership of household energy infrastructure.

Effect of Economic Growth on Household Electricity Consumption

In contrast to its effect on Household Customers, Economic Growth does not have a significant direct effect on Household Electricity Consumption. The coefficient is −17.0808 with a probability value of 0.1693. This finding indicates that economic growth alone does not significantly alter household electricity consumption when Population Density and Household Customers are controlled for.

One possible explanation concerns the aggregate nature of regional GDP growth. Economic growth reflects the performance of multiple economic sectors, including manufacturing, trade, construction, and services. An increase in regional GDP does not necessarily translate immediately into increased electricity consumption within existing households. The electricity demand generated by economic expansion may instead be concentrated in commercial and industrial sectors rather than directly affecting household electricity consumption.

The negative but statistically insignificant coefficient may also reflect improvements in household energy efficiency. Rising income can enable households to replace older appliances with more energy-efficient technologies, including LED lighting, inverter-based air conditioners, and energy-efficient refrigerators. Consequently, improvements in household purchasing power may not necessarily produce proportional increases in electricity consumption per existing household.

Another explanation is the potential time lag between economic growth and household electricity demand. Changes in regional economic conditions may require intermediary processes, such as housing development, household formation, and new electricity connections, before their effects become observable in aggregate household electricity consumption.

The mediation results provide further evidence for this mechanism. Although Economic Growth does not have a significant direct effect on Electricity Consumption, it significantly affects Household Customers, which in turn has a strong positive effect on Electricity Consumption. This indicates that the influence of economic growth is transmitted through the expansion of the household electricity customer base.

The finding is consistent with Diniari et al., who report that aggregate economic growth does not necessarily have a direct effect on household energy expenditure when intermediary factors are considered. It also complements Bazán Navarro et al. (2024) and Haryanti et al. (2024) by demonstrating that economic growth may operate through the expansion of electricity access and customer numbers rather than directly increasing electricity consumption among existing customers.

Effect of Household Customers on Household Electricity Consumption

Household Customers has the strongest direct effect on Household Electricity Consumption in Model 2, with a coefficient of 2689.6330, a t-statistic of 25.0730, and a probability value of 0.0000. The positive and highly significant relationship indicates that an increase in the number of household electricity customers is associated with a substantial increase in aggregate household electricity consumption.

This relationship is consistent with the basic logic of energy demand. Each additional electricity customer represents an additional point of household electricity consumption. Once a new household connection is established, electricity is used for lighting, refrigeration, communication devices, cooling equipment, and other domestic appliances. Consequently, expansion of the customer base increases aggregate electricity demand.

The strength of this relationship is particularly relevant in Java because the electricity infrastructure is relatively well established. The availability of an interconnected electricity system allows new residential connections to be incorporated into the existing electricity network. Therefore, the expansion of residential areas and new household connections can be translated relatively directly into additional electricity consumption.

The magnitude of the coefficient and the high t-statistic also establish Household Customers as the strongest explanatory variable in Model 2. More importantly, the variable functions as a central transmission mechanism linking Economic Growth to Household Electricity Consumption.

This finding supports previous evidence from Alfath et al. (2023), Sari et al. (2025), and Islam et al. (2022), which identifies expansion of the electricity customer base as an important determinant of increasing household energy consumption in developing regions.

Mediation Effect of Household Customers

The mediation analysis demonstrates two distinct transmission mechanisms. First, Household Customers does not significantly mediate the relationship between Population Density and Electricity Consumption. The indirect effect is −0.7692 with a Z-statistic of −0.6711 and a probability value of 0.5022. This result is consistent with the insignificant effect of Population Density on Household Customers.

Second, Household Customers significantly mediates the relationship between Economic Growth and Electricity Consumption. The indirect effect is 191.6420, with a Z-statistic of 4.1570 and a probability value of 0.0000. Because the direct effect of Economic Growth on Electricity Consumption is not significant, while its indirect effect through Household Customers is significant, the mediation pattern is classified as full mediation.

The findings therefore indicate that Economic Growth does not translate directly into higher household electricity consumption. Instead, its effect operates through an expansion of the household electricity customer base. Economic development first contributes to the expansion of residential demand and electricity connections, after which the increase in customers generates higher aggregate electricity consumption.

In contrast, Population Density operates through a different mechanism. Its significant direct effect on Electricity Consumption, combined with its insignificant effect on Household Customers, indicates that population concentration primarily increases electricity-use intensity among existing customers rather than expanding the number of registered customers.

Policy Implications

The findings provide several policy implications for electricity planning in Java. First, because Economic Growth affects household electricity consumption primarily through the expansion of Household Customers, electricity demand forecasting should consider residential development and customer growth in addition to aggregate GDP indicators. Indicators related to housing development, household formation, and suburban expansion can provide complementary information for estimating future household electricity demand.

Second, the significant direct effect of Population Density on Electricity Consumption highlights the importance of demand-side management in densely populated urban areas. Energy-efficiency measures targeting household appliances and densely occupied residential buildings may help manage increasing electricity demand associated with population concentration.

Third, the findings highlight the need for coordination between spatial planning and electricity infrastructure planning. Areas experiencing rapid residential and economic expansion may require corresponding improvements in electricity distribution infrastructure. Integrating demographic, residential, and economic indicators into regional electricity planning can therefore support more accurate demand projections and more efficient infrastructure allocation.

CONCLUSION

This study examined the relationships between Population Density, Economic Growth, Household Customers, and Household Electricity Consumption across six provinces in Java during 2020–2024. The findings demonstrate that demographic and economic factors influence household electricity consumption through different mechanisms.

Population Density has a positive and significant direct effect on Household Electricity Consumption but does not significantly affect the number of Household Customers. This finding indicates that increasing population concentration is more closely associated with greater electricity-use intensity among existing customers than with the expansion of the registered customer base. In contrast, Economic Growth has a positive and significant effect on Household Customers but does not have a significant direct effect on Household Electricity Consumption.

Household Customers has a positive and highly significant effect on Household Electricity Consumption and serves as the main transmission mechanism in the model. The mediation analysis further shows that Household Customers fully mediates the relationship between Economic Growth and Household Electricity Consumption, whereas no significant mediation is found for the relationship between Population Density and Household Electricity Consumption. Overall, the findings indicate that economic growth contributes to higher household electricity consumption primarily through the expansion of the electricity customer base, while population density operates mainly through increased consumption intensity among existing customers.

These findings suggest that future electricity demand planning in Java should integrate demographic density, economic growth, residential development, and household customer expansion rather than relying solely on aggregate economic indicators. Future implementation and service development should therefore prioritize integrated electricity-demand forecasting, particularly in rapidly urbanizing and expanding residential areas, while simultaneously strengthening energy-efficiency measures in densely populated regions. Further research may extend the analysis by incorporating household income, electricity tariffs, energy-efficiency adoption, housing characteristics, and regional infrastructure conditions to provide a more comprehensive explanation of household electricity demand dynamics.

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