

Electricity Consumption Dynamics in Indonesia: ARDL Approach

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Abstract

This study analyzes the determinants of per capita electricity consumption in Indonesia using consumption expenditure, foreign direct investment (FDI), trade, and inflation over the period 1980–2022. Given the increasing electricity demand driven by economic growth and structural transformation, understanding these determinants is essential for sustainable energy planning. This study contributes by providing evidence on how macroeconomic variables affect electricity consumption differently in the short run and long run in Indonesia. The findings imply that energy policy should distinguish between short-term demand management and long-term supply planning. The results show that, in the short run, consumption expenditure and trade have a positive and significant effect on electricity consumption, while inflation has a negative and significant impact. FDI has no significant effect in the short term. In the long term, FDI and inflation have a positive and significant effect on per capita electricity consumption, indicating that foreign investment strengthens industrial and infrastructure capacity, thereby increasing energy demand. Consumption and trade spending are not statistically significant in the long run, which indicates that the impact is temporary. These findings imply that electricity demand in Indonesia is influenced by both cyclical and structural factors. Therefore, energy policy should differentiate between short-term demand stabilization and long-term planning, particularly by promoting productive investment and maintaining macroeconomic stability.

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Introduction

Domestic energy plays a fundamental role in the modern economy because almost all household, industrial, and commercial activities depend on the availability of electrical energy as the main input of production. Various empirical studies show that reliable and sustainable access to electricity contributes significantly to increased productivity, smoother production processes, and overall economic growth. A positive relationship between electricity consumption and economic growth has been empirically demonstrated across various regional contexts, where increased electricity consumption serves as a driver of economic activity and national output expansion (Majewski et al., 2022; Mutumba et al., 2024). Similar evidence from Indonesia indicates that electricity consumption is closely associated with economic growth and macroeconomic performance, highlighting the important role of electricity in supporting economic development (Prastowo & Damayanti, 2022). Electrical energy is classified as secondary energy because it is produced through the conversion of primary energy sources such as coal, oil and gas, nuclear power, and renewable energy. Therefore, the level of electricity consumption is strongly influenced by macroeconomic conditions, energy demand structures, and the capacity and sustainability of primary energy supply within the national energy system, ultimately reflecting a country's ability to support long-term economic growth.

Among developing countries, Indonesia is the fourth most populous country in the world, with a population of approximately 287 million people and an annual population growth rate of about 0.7%, implying an average increase of nearly 2 million people per year. Rapid population growth places substantial pressure on socioeconomic conditions by increasing demand for employment, income distribution, food availability, and public services, potentially exacerbating poverty and inequality when development does not keep pace. In the energy sector, population growth significantly increases electricity demand through the growth of households and economic activities. However, the ability of the electricity system to meet rising demand is highly dependent on the availability of primary energy resources used for power generation. Empirical studies on energy systems suggest that limitations in primary energy supply can constrain electricity generation capacity and lead to persistent supply shortages. Evidence from large developing economies indicates that constraints in fossil fuel supply may limit long-term electricity availability, thereby widening the gap between electricity demand and supply and constraining per capita electricity consumption. In the Indonesian context, similar structural constraints may lead to persistent electricity shortages in the future if energy supply capacity does not expand in line with demographic growth (Basconcillo & Rimkute, 2023).

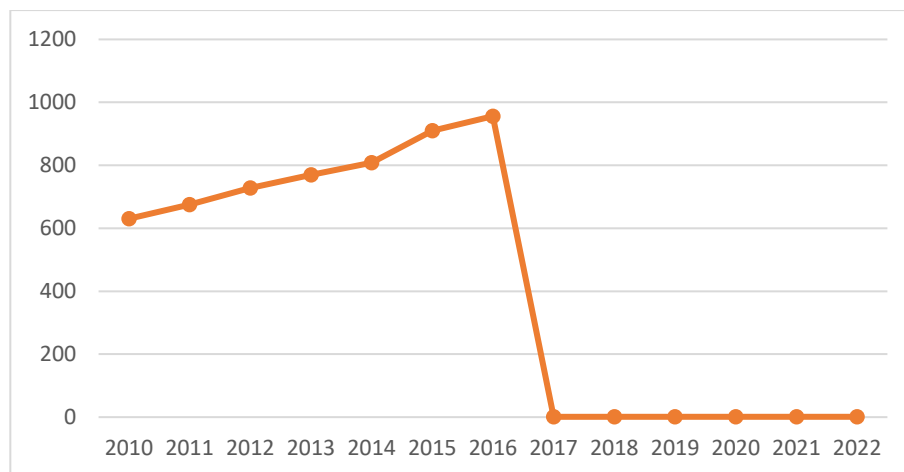


Fig 1. Graph of Electricity Consumption Per Capita in Indonesia in 2010-2022
Source: gatrik.esdm.go.id, 2022

As shown in Figure 1, per capita electricity consumption in Indonesia fluctuates over time. These fluctuations are influenced by various factors, including domestic conditions and global economic trends that affect energy demand and consumption patterns. In 1980, Indonesia's per capita electricity consumption, at 45.95 kWh per capita, was very low compared to that of both developed and developing countries. This can be attributed to relatively low income levels, which limited households' purchasing power and their ability to consume electricity in larger quantities. In addition, the limited availability of electricity infrastructure and access to modern energy services in many regions further constrained electricity consumption. As economic development progressed, improvements in income levels, industrial activities, urbanization, and infrastructure development contributed to a gradual increase in electricity demand. Since electricity is an essential input for household activities, industrial production, and public services, changes in electricity consumption often reflect broader economic and social developments within a country.

In addition, awareness of the importance of electricity for daily activities and economic productivity may also have been low at that time. In 1997 and 1998, Indonesia experienced declines in per capita electricity consumption to 328.38 kWh per capita and 327.72 kWh per capita, respectively. This decline was associated with the economic crisis that affected Asia during that period. The Asian financial crisis, which peaked at the end of 1997, led to a sharp depreciation of the rupiah, high inflation, and a decline in overall economic growth. The impact of the economic crisis was very significant, including production cuts, declines in industrial activity, and a reduction in overall consumption. In 2022, per capita electricity consumption in Indonesia increased to 1,173 kWh per capita, reaching its highest level. This increase was driven by the easing of the COVID-19 pandemic which allowed various sectors of the economy, including industry, business, and commercial activities, to resume operations, thereby increasing electricity demand. The substantial fluctuations in electricity consumption observed over time indicate that macroeconomic factors may play an important role in determining electricity demand in Indonesia.

Previous studies have investigated the relationship between electricity consumption and various macroeconomic indicators. For example, Majewski et al. (2022) found that electricity consumption contributes positively to economic growth, while Mutumba et al. (2024) reported that macroeconomic conditions significantly influence electricity demand. However, these studies primarily focused on cross-country evidence and did not specifically examine the Indonesian case. Moreover, existing studies generally provide limited evidence regarding the distinction between short-run and long-run effects of macroeconomic variables on electricity consumption. This limitation highlights the need for a more detailed country-specific analysis, as Indonesia has a distinct electricity demand structure shaped by its large population, industrial expansion, and macroeconomic fluctuations. Consequently, the applicability of previous findings to Indonesia remains uncertain. Therefore, the objective of this study is to examine the short-run and long-run effects of consumption expenditure, foreign direct investment (FDI), trade, and inflation on per capita electricity consumption in Indonesia using the autoregressive distributed lag (ARDL) approach. This study contributes to the existing literature by providing country-specific evidence from Indonesia, distinguishing between short-run and long-run dynamics, and offering policy-relevant insights for energy planning and sustainable electricity supply management.

Literature Review

The empirical literature on the macroeconomic determinants of per capita electricity consumption, particularly consumption expenditure, FDI, international trade, and inflation, provides the basis for a conceptual framework that explains the electricity demand dynamics and supports the formulation of empirical models for the present research. This study is grounded in energy demand theory, which posits that electricity consumption is influenced by economic activity, income levels, investment, and macroeconomic stability. Per capita electricity consumption is considered as an

important indicator of economic activity, industrial capacity, and people's welfare, particularly in developing countries. Therefore, a comprehensive understanding of the factors influencing electricity consumption is essential for the formulation of sustainable energy and macroeconomic policies. This review provides both conceptual and empirical foundations for the study, while also identifying research gaps that remain unanswered in the existing literature.

The modern energy economics literature consistently shows a strong relationship between electricity consumption and economic activity. In the context of developing countries, electricity consumption is not only viewed as a consequence of economic growth but also as a key driver of increased output and productivity. Recent systematic reviews indicate that the relationship between energy consumption and economic growth is generally bidirectional, indicating the strategic role of electricity in industrialization and structural economic transformation (AlKhars et al., 2020; Sarker, 2024). Other studies confirm that dependence on electricity consumption tends to be higher in developing countries than in developed countries, where energy efficiency is generally greater (Menegaki, 2021; Patel & Patel, 2022). These findings reinforce the use of per capita electricity consumption as a dependent variable in macroeconomic analysis.

On the demand side, electricity consumption expenditure reflects household income and purchasing power, which directly influences electricity consumption through increased use of electrical appliances and energy-intensive activities. Empirical studies demonstrate that consumption expenditure has a positive and significant effect on electricity consumption, particularly in the short term, as increased income encourages increased energy use in the household and commercial sectors (Menegaki, 2021). A review of the electricity economics literature also identifies consumption and income as the key determinants of electricity demand in developing countries. However, some studies suggest that the long-term effect of consumption expenditure on electricity consumption may weaken due to improvements in energy efficiency and consumption control policies, indicating a difference in impact across time horizons.

In addition, FDI is closely associated with electricity consumption through mechanisms such as industrial capacity expansion, infrastructure development, and technology transfer, which increase the energy use intensity, particularly in developing countries that serve as major investment destinations in energy-intensive sectors. FDI flows not only drive industrial output growth but also contribute to a structural and sustained increase in electricity demand, alongside the expansion of the manufacturing base and overall economic activity. Cross-country empirical evidence indicates that FDI contributes significantly to energy and electricity consumption in the long term, although its impact may potentially be indirect due to the time lags between investment realization and project implementation (Aali-Bujari & Venegas-Martínez, 2021). Panel data studies on electrical energy consumption in developing countries suggests that the influence of FDI on energy consumption becomes stronger in the long term, particularly when supported by macroeconomic stability and a conducive investment climate, whereas short-term effects are often insignificant (Ahmad et al., 2026). Studies on the impact of macroeconomic variables also confirms that FDI is an important determinant of the dynamics of long-term energy demand, especially in developing countries that are undergoing industrialization and structural transformation (Islam, 2023).

Similarly, international trade influences electricity consumption through increases in production scale of production, manufacturing activities, and logistics sector. Developing countries implementing trade-driven growth strategies generally experience increased demand for electrical energy. Recent studies present that increased trading activity contributes to higher electricity consumption through the scale effect and intensification of production (Nor & Mohamud, 2024). Similar findings have been reported in empirical studies on European countries, although the magnitude of the influence varied across time periods (Tariq et al., 2023). However, empirical evidence on the long-term impact of trade on electricity consumption remains inconsistent, as

structural economic changes and the adoption of energy-efficient technologies may reduce energy intensity.

In contrast, inflation affects electricity consumption, particularly through the mechanism of decreasing real purchasing power and increasing energy prices and production costs. In the short term, the increase in inflation tends to suppress electricity demand both from the household and production sectors. Households respond to inflation by reducing non-essential consumption, including electricity use, while firms face rising input costs that drive energy efficiency or reduce production activities, resulting in electricity consumption (Basconcillo & Rimkute, 2023; Purwanto et al., 2021). In the long term, the relationship between inflation and electricity consumption becomes more dynamic and not always negative. This is because the economies may adapt through adjustments to nominal income, economic growth, and energy and subsidy policies that mitigate the impact of rising prices. As a result, electricity consumption is more strongly determined by structural factors such as income and economic development than by inflationary pressures themselves (Safiah et al., 2021). However, previous studies did not always agree on the long-run effects of trade and inflation, suggesting that country-specific evidence remains necessary.

Although the literature on electricity consumption and macroeconomic variables continues to expand, a number of research gaps remain. First, studies analyzing long time periods in developing countries remain limited. Second, many studies do not explicitly distinguish the short-term and long-term impacts of consumption spending, FDI, trade, and inflation. Third, empirical evidence regarding the long-term effects of trade and inflation on electricity consumption remains inconsistent. These inconsistencies highlight the need for further empirical investigation to better understand the long-term relationship between macroeconomic variables and electricity consumption, particularly in developing countries such as Indonesia.

Methods

This study used secondary time-series data covering the period 1980-2022. Data on per capita electricity consumption, consumption spending, foreign direct investment, trade, and inflation were obtained from *the World Development Indicators* (WDI) and MacroTrends. The autoregressive distributed lag (ARDL) model is employed because it allows for the simultaneous estimation of both short-run and long-run dynamics of electricity consumption in response to macroeconomic changes over time.

Table 1 presents the operational definitions of the variables used in this study. Per capita electricity consumption (kWh) is employed as the dependent variable to represent electricity demand and energy utilization in Indonesia. The independent variables consist of consumption expenditure (PK), foreign direct investment (FDI), trade (TRADE), and inflation (INF), which are selected based on their theoretical and empirical relevance to electricity consumption. Consumption expenditure reflects household purchasing power and energy demand, FDI captures the effects of investment and industrial expansion, trade represents economic openness and production activities, while inflation reflects macroeconomic stability and changes in purchasing power. These variables are expected to influence electricity consumption through different transmission mechanisms in both the short run and the long run, thereby providing a comprehensive understanding of the determinants of electricity consumption in Indonesia.

The selection of variables is based on previous empirical studies that identify consumption expenditure, FDI, trade, and inflation as key macroeconomic determinants of electricity consumption. Moreover, these variables capture different channels through which macroeconomic conditions may affect electricity demand, including household consumption behavior, investment activities, trade expansion, and price dynamics. As such, their inclusion enables a more comprehensive assessment of the determinants of electricity consumption in Indonesia.

Table 1. Operational Definitions

Variable	Symbol	Definition	Source
Per Capita Electricity Consumption (kWh per capita)	<i>kWh</i>	The amount of electrical energy used directly or indirectly from energy sources can be divided by the number of people in the region during a year.	MacroTrends
Consumption Expenditure (Current US\$)	<i>PK</i>	Consumption expenditure is a term that refers to the amount of money spent by individuals on the purchase of goods and services. In economics, it can also be referred to as residual income that can be saved.	World Development Indicators
Foreign Direct Investment (Current US\$)	<i>FDI</i>	Foreign direct investment (FDI) is an investment made by a company or individual from one country to another with the aim of gaining direct control over assets or businesses in the country in which they are invested.	World Development Indicators
Trade (Merchandise exports current US\$)	<i>TRADE</i>	Trade refers to the transactions that involve the sale of goods and services between individuals, organizations, or countries. Trade has become one of the important components in the economic life of a country along with the advancement of the times and technology.	World Development Indicators
Inflation (%)	<i>INF</i>	Inflation refers to an increase in the price of goods consistently over a certain period of time, if the increase spreads or causes an increase in the price of other goods	World Development Indicators

ARDL approach, developed by (Pesaran & Shin, 1999) and further formalized by (Pesaran et al., 2001), is an econometric technique widely used to examine short-run and long-run relationships in time-series data. The ARDL framework is particularly suitable for small sample sizes and allows the inclusion of variables with mixed orders of integration, $I(0)$ and $I(1)$, provided that none is integrated of order $I(2)$. One of its key advantages is its flexibility in assigning different optimal lag lengths to each variable, selected using information criteria such as the Akaike Information Criterion (AIC) or the Schwarz Bayesian Criterion (SC), thereby improving model specification (Pesaran et al., 2001). The ARDL approach has also been widely applied in Indonesian macroeconomic studies to estimate both short-run and long-run relationships among economic variables, demonstrating its suitability for analyzing dynamic economic relationships (Bagaskara, 2023). Prior to estimation, unit root properties are examined using the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests under alternative deterministic specifications.

To test for the existence of a long-run equilibrium relationship among the variables, this study employs the ARDL bounds testing approach to cointegration, which relies on an F-statistic comparison with critical value bounds proposed by Pesaran et al. (2001) and (Narayan & Smyth, 2005) for small samples. Once cointegration is established, the ARDL model enables simultaneous estimation of long-run coefficients and short-run dynamics through an error correction mechanism. Model stability is assessed using the Cumulative Sum (CUSUM) and Cumulative Sum of Squares (CUSUMQ) tests. Recent empirical studies confirm that the ARDL bounds testing approach provides consistent and reliable estimates in energy-macroeconomic models, particularly in developing-country contexts (Ali et al., 2022). The ARDL method is appropriate for this study because electricity consumption is a demand variable that adjusts over time in response to changes in household expenditure, foreign direct investment, trade, and inflation. In the Indonesian economy, these macroeconomic variables affect electricity demand through different transmission channels and

adjustment speeds. Consumption expenditure influences household electricity use, FDI affects industrial expansion and infrastructure development, trade changes production intensity, and inflation alters purchasing power and production costs. Because these effects may appear immediately in the short run but become stronger, weaker, or change direction in the long run, the ARDL approach is suitable for capturing both short-run and long-run relationships within a single model.

The following ARDL equations in general are as follows:

$$\Delta \ln KWH = \alpha_0 + \sum_{i=1}^p \alpha_1 \Delta \ln KWH_{t-i} + \sum_{i=0}^q \alpha_2 \Delta \ln PK_{t-i} + \sum_{i=0}^q \alpha_3 \Delta \ln FDI_{t-i} + \sum_{i=0}^q \alpha_4 \Delta \ln TRADE_{t-i} + \sum_{i=0}^q \alpha_5 \Delta \ln INF_{t-i} + \lambda ECT_{t-1} + \varepsilon_t \quad (1)$$

In this model, *kWh* represents per capita electricity consumption, *PK* denotes consumption expenditure, *FDI* refers to foreign direct investment, *TRADE* represents international trade, and *INF* denotes inflation. All variables are expressed in natural logarithmic form (ln) to stabilize variance and facilitate interpretation in terms of elasticity. The term ε_t represents the error term capturing other factors not included in the model. Here, Δ denotes the first difference and (ln) represents the natural logarithm. The coefficients of the differenced variables represent short-run effects of the independent variables on electricity consumption. The term ECT_{t-1} is the error correction term derived from long-run equilibrium equation, and its coefficient reflects the speed of adjustment toward the long-run equilibrium. A negative and statistically significant coefficient of the ECT_{t-1} indicates the existence of a stable long-run relationship among the variables.

Result and Discussion

Data processing in this study was carried out using the Eviews 10 application to obtain accurate results and explain the variables carefully. The dependent variable is Electricity Consumption Per Capita in Indonesia, while the independent variables include Consumption Expenditure, Foreign Direct Investment, Trade, and Inflation in 1980-2022. Economic analysis, based on statistical analysis, focuses on evaluating the expected signs suggested by economic theory or prior empirical research.

Table 2. ARDL Regression Results

Variable	Coefficient	t-Statistic	Probability
Consumption Expenditure	-1992.855	-0.402646	0.6920
Foreign Direct Investment	2649.980	0.544190	0.5930
Trade	-2.394131	-1.421649	0.1722
Inflation	18.55246	0.043947	0.9654
C	-1191.505	-0.028406	0.9777
R-Squared	0.856886	Mean Dependent	24337.85
Adjusted R-Squared	0.697870	Hannan-Quinn Criterion.	22.41233
Prob(F-Statistic)	0.000357	Durbin Watson Statistic	2.087882

Based on the estimation results in Table 2, the best model of the *Autoregressive Distributed Lag* (ARDL) test was the ARDL model (3, 4, 1, 4, 4). This study indicates that the important variables in this model are Electricity Consumption Per Capita in the previous three years, Consumption Expenditure in the previous four years, Foreign Direct Investment in the previous year, Trade in the previous four years, and inflation in the previous four years.

Table 3. Short-Term Test

Variable	Coefficient	t-Statistic	Prob.
D(Consumption Expenditure(-1))	10684.45	2.746476	0.0133
D(Consumption Expenditure(-2))	21.816d78	0.005577	0.9956
D(Consumption Expenditure(-3))	7173.625	1.797161	0.0891
D(Foreign Direct Investment)	2649.980	0.841046	0.4114
D(Trade)	-2.394131	-1.808921	0.0872
D(Trade(-1))	8.857183	5.974193	0.0000
D(Trade(-2))	0.882570	0.353493	0.7278
D(Trade(-3))	7.500608	3.963904	0.0009
D(Inflation)	18.55246	0.069258	0.9455
D(Inflation(-1))	-2326.655	-4.783672	0.0001
D(Inflation(-2))	-1691.787	-4.155824	0.0006
D(Inflation(-3))	-6375479	-2.413551	0.0267
CointEq(-1)*	-0.748139	-6.577214	0.0000

As shown in Table 3, the value of CointEq (-1) is -0.748139 or in the range of 0 to 1 and has a negative value. This means that in the short term, the model built is valid and has short-term cointegration. Empirical research suggests that a negative and significant error correction term (ECT) coefficient is a major indicator that the economic system is undergoing short-term adjustments towards long-term equilibrium after a shock. The ARDL-ECM study in the Indonesian macroeconomic context found that negative and significant ECT reflects an effective error correction mechanism, indicating model stability and econometric validity (Suripto et al., 2025). Similar findings were also demonstrated in cross-country studies of developing countries, where ECT values were negatively valued at less than 1, indicating a rapid pace of adjustment to long-term equilibrium, while confirming the existence of cointegration in the short term (Lim, 2024). Modelling in real and energy sector studies, ARDL-ECM has also been shown to effectively capture short-run dynamics. A negative and significant ECT values are used as evidence that short-term deviations will be systematically corrected in the following period, thereby supporting model validity and parameter stability (Khanal, 2021; Thapa, 2024). Research with the ARDL-ECM model based on various sectors, including trade, finance, and development, has consistently concluded that negative and significant ECT not only signals long-term cointegration, but also indicates the existence of stable and reliable short-term relationships for policy inferences (Dangal, 2022; Ngcobo et al., 2023).

Table 3 shows that the consumption expenditure variable has a positive and significant impact on per capita electricity consumption in Indonesia, considering the Prob value of $0.0133 < 0.05$. As a result, consumption expenditure one period ago showed a significant positive influence on electricity consumption per capita. The positive and statistically significant effect of lagged consumption expenditure on per capita electricity consumption in Indonesia is consistent with energy consumption theory, which posits that electricity demand is a derived demand that increases with higher household income and expenditure through greater use of energy-intensive goods and services. As household consumption expands, electricity is increasingly used to support daily activities, ownership of electrical appliances, and improved living standards. From an empirical perspective, this finding aligns with evidence that household consumption expenditure is a key determinant of residential electricity demand, particularly in developing and emerging economies. Using an ARDL framework, (Bohlmann & Inglesi-Lotz, 2021) demonstrate that disposable income has a positive and significant long-run effect on household electricity consumption, confirming that electricity behaves as a normal good. At the household level, microdata-based studies further reinforce this relationship. Rasyid & Kristina (2021) show that electricity constitutes the largest share of household energy expenditure in Indonesia, underscoring the strong linkage between consumption behavior and electricity use (Rasyid & Kristina, 2021). In addition, Chudy-Laskowska

& Pisula (2023) provide cross-country evidence for the European Union, demonstrating that household final consumption expenditure is the primary driver of electricity demand across different energy sources (Chudy-Laskowska & Pisula, 2023). The empirical result that lagged consumption expenditure positively influences per capita electricity consumption in Indonesia is theoretically sound and empirically supported. It reflects the adjustment process whereby increases in household spending gradually translate into higher electricity usage, consistent with both short-run consumption dynamics and long-run energy demand behavior observed in recent literature. This result indicates that increases in household expenditure directly led to higher electricity usage, reflecting the role of consumption as a driver of energy demand.

The results in the Table 3 show that FDI has a positive but insignificant effect on per capita electricity consumption in Indonesia, which is indicated by a probability value of 0.4114 (> 0.05). These findings indicate that although increases in FDI are associated with higher electricity consumption, the influence has not been statistically strong enough in the observation period. The FDI literature on energy explains that although FDI theoretically has the potential to increase energy demand through the industrial expansion and increased production capacity; however, these impacts are often indirect and take time to realize (Darwin et al., 2022; Rahaman et al., 2022). Some empirical studies have found that the influence of FDI on energy or electricity consumption tends to be stronger in the long term than in the short term. Research in developing countries shows that FDI does not always have a significant impact in the initial period as foreign investment generally requires time for infrastructure development, technology installation, and full operational stages before significantly increasing energy consumption (Aali-Bujari & Venegas-Martínez, 2021; Darwin et al., 2022). These positive but insignificant findings are also consistent with studies of the energy sector in developing Asia, which show that FDI does not necessarily increase electricity consumption when investment is not concentrated in energy-intensive sectors (Latief & Lefen, 2019). Furthermore, the cross-country panel study also confirms that macroeconomic stability, industrial structure, and domestic energy policies play an important role in determining whether FDI has a significant impact on energy consumption. Therefore, the empirical results of this study reinforce the view that FDI has the potential to increase electricity consumption, but its effects are contextual and not always significant in the short term, according to the findings from (Adebayo et al., 2021). This suggests that the impact of FDI requires time to materialize, particularly through industrial expansion and infrastructure development.

The results of the estimation in Table 3 show that the Trade has a positive and significant effect on electricity consumption per capita in Indonesia, as evidenced by a probability value of 0.0000 (< 0.05). These findings indicate that trading activity plays an important role in increasing the electricity demand. Theoretically, this positive relationship between international trade and electricity consumption can be explained through increased production activity, expansion of industrial sectors, and overall economic growth associated with higher levels of exports and imports. Trade encourages firms to increase production capacity, which in turn increases the demand for electrical energy as the main input of the production process. Empirical studies by Darwin et al. (2022) show that increased trade openness in developing Asian countries significantly boosts energy consumption, including electricity, through the path of industrialization and economic growth (Darwin et al., 2022; Satrianto et al., 2025). These findings are consistent with the research of Rahaman et al. (2022), who report that increased trade activity contributes to higher electricity consumption as the expansion of the export-oriented manufacturing and services sector tends to be energy-intensive, international trade is often the main catalyst for increased energy demand due to the increasing scale of production and use of electricity-based technologies (Rahaman et al., 2022; Satrianto et al., 2025). Studies from (Hussain & Zhou, 2022) confirm that trade openness strengthens the relationship between economic growth and energy consumption. Countries with high levels of trade tend to experience a significant increase in energy consumption due to the increase in logistics, transportation, and processing

industry activities that require a stable and large supply of electricity (Hussain & Zhou, 2022; Tariq et al., 2023). The findings of this study show that trade activities are an important determinant of per capita electricity consumption in Indonesia, as increased exports and imports drive higher electricity demand through intensified economic and production activities. This reflects that increased trade activity leads to higher production intensity, which requires more electricity consumption. Strong statistical significance indicates that trade has a structural role in shaping national electrical energy consumption patterns.

As shown in Table 3, inflation has a negative but significant impact on per capita electricity consumption in Indonesia, In the short-term inflation has a probability of less than 0.05 showing that inflation in the past three periods also has a negative and significant impact on per capita electricity consumption. This implies that a one-unit increase in inflation in the previous period is associated with a decrease in per capita electricity consumption of approximately 2,326.655 units. The results of the study showing that inflation has a negative and significant effect on per capita electricity consumption in Indonesia are in line with macroeconomic theory and the empirical energy literature. Theoretically, inflation increases the cost of living for households and the production costs of the industrial sector, thereby reducing real purchasing power and encouraging saving behavior, including in the use of electrical energy. Empirically, various studies have found that rising inflation suppresses energy consumption in the short term, particularly in developing countries. ARDL-based studies in Turkey shows that inflation has a negative and significant influence on energy consumption, as price pressures encourage households and businesses to reduce energy use in response to the rising cost of living (Bala et al., 2024; Olusola et al., 2022). Similar findings are reported in cross-Asian studies, which show that inflation negatively impacts energy consumption, especially in the short term, as inflation lowers real consumption and increases economic uncertainty (Matsumoto et al., 2021; Satrianto et al., 2025). The study confirms that inflationary pressures cause households and industries to postpone consumption, including electricity use. Furthermore, empirical studies on the household sector show that rising prices and inflationary pressures encourage energy conservation behaviors, in which households reduce their electricity use to adjust their consumption budgets (Matsumoto et al., 2021). This supports the results of the present study that inflation in the previous period had a significant impact on reducing per capita electricity consumption in the current period. This indicates that rising prices reduce purchasing power, leading to lower electricity consumption in the short-term. The empirical findings of this study are consistent with the previous literature, which confirms that inflation is an important macroeconomic factor that affects electricity demand through a mechanism of decreasing purchasing power and increasing production costs.

The difference between short-run and long-run results can be explained by the adjustment process of economic variables. In short term, electricity consumption is influenced by immediate changes in income, prices, and economic activity. However, in the long term, structural factors such as industrial development, investment realization, and technological changes play a more dominant role, leading to different impacts of macroeconomic variables over time.

Table 4. Long-Term Test

Variable	Coefficient	Std. Error	t-Statistic	Prob*
Consumption Expenditure	-3091.779	4122.050	-0.75005	0.4629
Foreign Direct Investment	16193.63	6579.059	2.46139	0.0242
Trade	-1.265243	0.916263	-1.380874	0.1842
Inflation	4313.305	1875.216	2.300165	0.0336
Constanta	-1592.626	56119.22	-0.02837	0.9777

Based on the results of the long-term ARDL estimate in Table 4, only two variables, foreign direct investment (FDI) and inflation, have a statistically significant effect on per capita electricity

consumption in Indonesia in the long-term. FDI has a probability value of 0.0242 (<0.05). Theoretically and empirically, this positive relationship reflects that increased foreign investment flows encourage the expansion of economic activities, industrialization, and increased production capacity, ultimately increasing the electrical energy demand. These findings are in line with the research of Darwin et al. (2022) reporting that in the long term, FDI significantly increases energy consumption in developing Asian countries through increased industrial activity and economic growth (Aali-Bujari & Venegas-Martínez, 2021; Darwin et al., 2022). In addition, research by Islam (2023) found that FDI has a positive and significant influence on long-term energy consumption, particularly in developing countries, as foreign investment tends to be concentrated in energy-intensive manufacturing and infrastructure sectors (Islam, 2023).

The inflation also has a positive and significant influence on electricity consumption per capita in the long run, with a probability value of 0.0336 (< 0.05). Economically, the positive relationship between inflation and electricity consumption in the long run can be explained through the mechanism of nominal growth and an increase in aggregate economic activity. In the long run, inflation is often associated with higher nominal income, expanded demand, and increased production; therefore, the consumption of electrical energy has an impact on increasing national output. Olusola, et al., (2022) research shows that in the long run, inflation can drive energy consumption along with increased economic activity and nominal income adjustments, although the short-term effects can be contractive (Islam, 2023; Olusola et al., 2022). Furthermore, Munteanu & David (2023) explain that persistent inflation reflects increased energy costs and higher economic activity. In the long term, it can be associated with increased energy consumption, especially electricity, by both households and the industrial sector (Munteanu & David, 2023; Satrianto et al., 2025). Thus, the findings suggest that, in the long run, inflation no longer suppresses electricity consumption but instead reflects more expansive economic conditions, where rising prices coincide with increased per capita electricity consumption.

Meanwhile, the Consumption and Trade Expenditure has a probability higher than 0.05 with a negative coefficient so that it does not have a significant effect on the Electricity Consumption per capita variable. Trade does not have a significant impact on per capita electricity consumption in the long term. These results show that trade dynamics do not directly affect per capita electricity consumption patterns.

Conclusion

This study aims to identify the short-run and long-run determinants of per capita electricity consumption in Indonesia using an ARDL approach. The results show that consumption expenditure significantly increases electricity consumption only in the short term, while its long-term effect is not significant, indicating delayed behavioral responses and the influence of energy policies. Foreign direct investment does not affect electricity consumption in the short run but has a positive and significant impact in the long run, reflecting the gradual role of investment in expanding industrial capacity and infrastructure. Trade has a positive and significant effect in the short term due to its direct impact on economic activity, but its influence diminishes in the long term as structural adjustments, technological change, and energy regulation take place. Inflation reduces per capita electricity consumption in the short term through declining purchasing power, but in the long term it increases electricity consumption as the economy adapts through income growth and changing consumption patterns. These findings imply that electricity demand management in Indonesia should distinguish between short-term demand stabilization and long-term energy planning, with greater emphasis on investment-driven capacity expansion and consistent energy policy frameworks. This study is limited to a macro-level time series analysis and does not account for regional disparities or sectoral electricity use. Future research should incorporate disaggregated data, regional analysis, and the role of renewable energy adoption to better capture structural

changes in electricity demand. These findings contribute to the literature by providing empirical evidence on the dynamic relationship between macroeconomic variables and electricity consumption in Indonesia, particularly by distinguishing short-run and long-run effects using the ARDL approach. This study also supports energy demand theory by confirming that macroeconomic variables influence electricity consumption differently across time. In the Indonesian context, electricity demand reflects both economic activity and structural economic conditions.

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Declarations

Author contribution : Thangraj Venkatesan was responsible for the overall research design and conceptual framework. Suropto led the empirical analysis, interpretation of results, and manuscript preparation, as well as coordination among authors. Natasya Cut Dian Amelia participated in data collection, data processing, and preliminary analysis. Azkal Azkiya Athfal contributed to technical support, model estimation, and manuscript revision. All authors reviewed and approved the final manuscript.

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Additional information

We as authors acknowledge that this work has been written based on ethical research that conforms with the regulations of our universities and that permission was obtained from relevant institutions when collecting data

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