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What drives fossil fuel consumption in Indonesia? Evidence from a macroeconomic perspective

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Abstract
Fossil fuels play a crucial role in economic activity in developing countries, including Indonesia. Currently, fossil fuels dominate and serve as the primary energy source, accounting for approximately 80% of the country's energy needs. Amidst fluctuating macroeconomic dynamics, fossil fuel consumption has experienced a significant increase. In this paper, we investigate the effects of macroeconomic indicators, namely economic growth, urbanization, and trade openness, on fossil fuel consumption in Indonesia. The study uses data from 1990 to 2024 sourced from Our World in Data and the World Bank. The analysis used multiple linear regression to examine the influence between variables, along with classical assumption tests. The study found that economic growth had a positive and significant effect. Urbanization had a positive and significant effect. Trade openness was also found to have a positive and significant effect on fossil fuel consumption. The largest increase in fossil fuel consumption was driven by urbanization. These findings have important implications for the formulation of future energy policies.

Keywords: Fossil Fuel Consumption, Economic Growth, Urbanization, Trade Openness.

Abstrak
Bahan bakar fosil memainkan peran penting dalam aktivitas ekonomi di negara berkembang termasuk Indonesia. Hingga saat ini, sekitar 80% bakan bakar fosil telah mendominasi dan menjadi energi utama. Di tengah pergerakan makroekonomi yang berfluktuasi, konsumsi bahan bakar fosil mengalami peningkatan yang signifikan. Dalam paper ini, kami menginvestigasi indikator makroekonomi yakni pertumbuhan ekonomi, urbanisasi, dan keterbukaan perdagangan terhadap konsumsi bahan bakar fosil di Indonesia. Studi menggunakan data dari periode 1990 hingga 2024 yang bersumber dari Our World in Data dan World Bank. Analisis dilakukan menggunakan regresi linear berganda dalam menguji pengaruh antar variabel disertai pengujian asumsi klasik. Hasil kajian menemukan pertumbuhan ekonomi berpengaruh positif dan signifikan. Urbanisasi ditemukan berpengaruh positif dan signifikan. Berikutnya keterbukaan perdagangan ditemukan berpengaruh berpengaruh positif dan signifikan pada konsumsi bahan bakar fosil. Peningkatan konsumsi bahan bakar fosil terbesar didorong oleh faktor urbanisasi. Temuan ini memberikan implikasi penting bagi perumusan mengenai perumusan kebijakan energi di masa yang akan datang.

Kata kunci: Konsumsi Bahan Bakar Fossil, Pertumbuhan Ekonomi, Urbanisasi, Keterbukaan Perdagangan.

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1. Introduction

Energy has long been an essential component of modern economic development. Almost all economic activities, including production, distribution, transportation, and household consumption, rely on energy to sustain productivity and ensure long-term viability (Wang et al., 2019). Energy sources can generally be categorized into two types: non-renewable and renewable. Among these, fossil fuels are the predominant energy source used in many countries, primarily due to their abundant supply, relative accessibility, and established infrastructure (Shahbaz et al., 2017). However, the reliance on fossil fuels poses significant environmental challenges, including carbon emissions that threaten future sustainability (Salim & Shafiei, 2014). As a result, numerous countries are beginning to shift towards more environmentally friendly energy systems.

This transition to sustainable energy is particularly challenging for developing nations like Indonesia. Such countries often face constraints related to human resources and technological infrastructure. In contrast, developed nations typically benefit from more robust technological and innovation support (Degirmenci et al., 2025). Indonesia is blessed with abundant natural resources, one of which is fossil fuels. It's no surprise that its energy landscape is still dominated by fossil fuels, particularly coal, gas, and oil. From an economic perspective, this will provide immediate benefits, namely cheaper raw materials, which will accelerate economic growth.According to the Energy Institute (2025) report, Indonesia's fossil fuel consumption has notably surged over the past 35 years (see Figure 1). In the early 1990s, fossil fuel consumption was 3,148.65 kWh, which rose to 7,575.91 kWh by 2020, marking a 140.6% increase. Consumption did see a decline in 2021 due to the impacts of COVID-19, dropping to 6,896.36 kWh, but it sharply rebounded to 9,393.86 kWh in 2024.

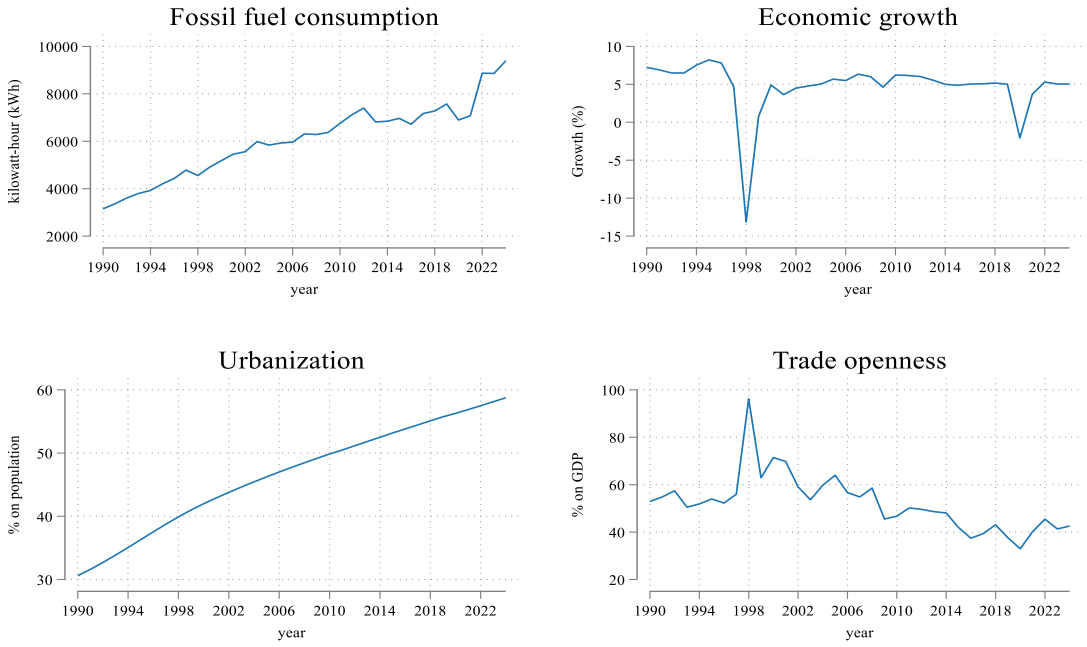

Figure 1. Development of fossil fuel consumption and macroeconomics in Indonesia for the period 1990-2024

The escalating consumption of fossil fuels presents a significant challenge that warrants comprehensive investigation. Numerous studies have shown that energy demand is closely linked to a country's macroeconomic conditions. Economic growth is often identified as a key determinant, as it is associated with increased production and industrial activity, which require higher energy inputs (Acheampong et al., 2021). Similarly, urbanization can drive energy consumption, particularly in developing countries, where rapid population shifts toward urban areas increase transportation demand, infrastructure development, electricity use, and lifestyle changes (Bakirtas & Akpolat, 2018; Warsame, 2022). Trade openness also plays an important role by facilitating export–import activities, expanding production capacity, and increasing energy demand to support economic integration (Arif et al., 2017; Han et al., 2022; Murshed, 2020). Therefore, this study addresses the following research question: Do macroeconomic indicators contribute to the rising fossil fuel consumption in Indonesia?

Despite these theoretical linkages, empirical evidence on the relationship between macroeconomic factors and fossil fuel consumption remains inconclusive. For instance, Bakirtas & Akpolat (2018) report a negative effect of economic growth on fossil energy consumption in emerging markets, whereas Shahbaz et al. (2022) find a positive relationship in China. Similarly, urbanization has been found to increase energy consumption (Shahbaz et al. 2017), yet other studies report a negative impact, such as in Somalia (Warsame, 2022). In the case of trade openness, Arif et al. (2017) show that greater openness increases fossil energy use in Southeast Asia, while Shahbaz et al. (2015) find the opposite effect in Malaysia. These mixed findings suggest the presence of context-specific dynamics and indicate that the effects of macroeconomic variables on fossil fuel consumption are not uniform across countries.

This study contributes to the energy literature in several important ways. First, it addresses a critical empirical gap by focusing explicitly on fossil fuel consumption, rather than aggregate energy use, thereby providing a more precise understanding of non-renewable energy dynamics in Indonesia. As a developing country, Indonesia's energy system remains heavily dependent on fossil fuels, accounting for approximately 80 percent of total energy consumption derived from coal, oil, and gas. Existing studies have largely examined the relationship between economic growth and overall energy consumption (Darrian et al., 2023; Ikhsan et al., 2022; Nugraha & Osman, 2017; Rahmayani et al., 2025) or have focused on renewable energy issues (Arif et al., 2017; Aswadi et al., 2023; Susilowati et al., 2023). Thus, there is an urgent need for studies that specifically investigate the factors influencing fossil fuel consumption in Indonesia.

Second, this study offers a more comprehensive analysis by integrating economic growth, urbanization, and trade openness as macroeconomic indicators potentially affecting fossil fuel consumption. These indicators are essential for understanding the dynamics of economic development, demographic changes, and international trade integration in Indonesia. Third, this study contributes by providing updated and context-specific evidence for Indonesia. Therefore, this study aims not only to provide empirical contributions but also to offer valuable insights related to the energy landscape in Indonesia.

2. Research Method

This study employs time series data covering the period from 1990 to 2024 for Indonesia. Indonesia is selected as the case study due to its strategic position as a developing country in Asia, characterized by relatively stable economic growth, rapid urbanization, and integration into the global trade system. In addition, Indonesia remains highly dependent on fossil energy. The analysis was conducted using three independent variables: economic growth, urbanization, and open trade. Fossil fuel consumption is the dependent variable. The research data uses an operational definition of fossil fuel consumption using the average energy consumption from coal, oil, and gas per capita in kilowatt-hours. Economic growth is proxied the GDP growth rate based on the 2015 constant year measured as a percentage. Urbanization is measured as the percentage of the urban population to the total population. Meanwhile, trade openness is measured as the ratio of total exports and imports to GDP in percentage. We use fossil fuel consumption data from Ritchie & Rosado (2017) through the Our World in Data platform, while other variable data are sourced from the World Bank. The model function in this study can be formulated as follows:

$$FC = f(EG, URB, TOP) \quad (1)$$

Based on equation (1), it can be set in econometric form as follows:

$$FC_t = \delta_0 + \delta_1 EG_t + \delta_2 URB_t + \delta_3 TOP_t + \varepsilon_t \quad (2)$$

Where FC, EG, URB, and TOP represent fossil fuel consumption, economic growth, urbanization, and trade openness. t is a time series, δ_0 is a constant, $\delta_1 - \delta_3$ are the variable parameter coefficients, and ε is white noise. In equation (2), the FC variable is transformed into a natural logarithm so that the implied regression model is log-linear. This transformation aims to facilitate the interpretation of the coefficients in percentage form. To obtain unbiased and efficient estimation results, the regression model needs to fulfill several classical assumptions such as normality, autocorrelation, heteroscedasticity, and multicollinearity. The equation model (2) is estimated using the STATA statistical application program. The expected signs are $\frac{\partial FC}{\partial EG} > 0$, $\frac{\partial FC}{\partial URB} > 0$, and $\frac{\partial FC}{\partial TOP} > 0$

3. Results and Discussion

3.1. Results

Table 1 presents descriptive statistics of the research data. Fossil fuel consumption (FC) had an average of 6037.63 kWh with a standard deviation of 1570.36 kWh. Economic growth (EG) grew by an average of 4.73%with a standard deviation of 3.611%. Urbanization (URB) had an average of 46.57% with a standard deviation of 8.35%. Meanwhile, trade openness (TOP) showed an average of 52.208% with a deviation of 11.84%. The presentation of these descriptive statistics data shows significant economic dynamics during the data observation, especially in fossil fuel consumption which reached 9393.86 kWh in 2024.

Table 1. Descriptive statistics

Variables	Mean	Std. dev	Min	Max
FC (kWh)	6037.63	1570.36	3148.652	9393.86
EG (%)	4.723	3.611	-13.126	8.220
URB (%)	46.579	8.358	30.594	58.750
TOP (%)	52.208	11.841	32.972	96.186

Before interpreting the study results, it is necessary to first test the classical assumptions. This testing stage is necessary because the research model uses the Ordinary Least Squares (OLS) estimator. Table 2 shows several assumption tests such as normality, autocorrelation, heteroscedasticity, and multicollinearity. The normality test using the Jarque-Berra approach, namely 0.049 with a p-value of 0.975, concluded that the residuals are normally distributed. The autocorrelation test using the Breusch-Godfrey LM test approach found a statistical figure of 1.869 with a p-value of 0.392, thus concluding there is no correlation between the residuals. Next, the heteroscedasticity test using the Breush-Pagan approach was 1.58 with a p-value of 0.208, concluding homoscedasticity. Table 3 shows the multicollinearity test using the Variance Inflation Factor (VIF) found independent variables <10, thus concluding there is no violation of multicollinearity in the model. Based on this test, the study model estimation has fulfilled the Best Linear Unbiased Estimator (BLUE) elements.

Table 2. Classical assumption testing

Testing	Method	Statistics	P-value
Normality	Jarque-Bera	0.049	0.975
Autocorrelation	Breusch-Godfrey LM	1.869	0.392
Heteroskedasticity	Breuch-Pagan	1.580	0.208

Table 3. Multicollinearity test

Variables	VIF	1/VIF
EG	2.50	0.40
URB	1.94	0.51
TOP	1.73	0.57
Mean VIF	2.06	

Table 4 shows the regression estimation results of the fossil fuel consumption model influenced by economic growth, trade openness, and urbanization. In interpreting a log-linear model, there is a rule of thumb in which the coefficient of the variable is multiplied by 100 (Gujarati & Porter, 2009). Economic growth is found to have a coefficient of 0.012, where a 1% increase in economic growth can increase fossil fuel consumption by 1.2%, assuming ceteris paribus. Statistically, the effect of economic growth is significant at the 1% level. Urbanization is found to have a positive and significant effect at the 1% level. If urbanization increases by 1%, then fossil fuel consumption will increase by 3.7%, assuming ceteris paribus. Trade openness is found to have a coefficient of 0.005, where a 1% increase in trade openness will increase fossil fuel consumption by 0.5%, assuming ceteris paribus. The effect of trade openness is statistically significant at the 1% level.

Table 4. Results of the fossil fuel consumption model

Variables	Coefficient	Std. error	t-stat	P-value
EG	0.012***	0.002	4.34	0.000
URB	0.037***	0.001	27.83	0.000
TOP	0.005***	0.001	4.87	0.000
C	6.608***	0.117	56.07	0.000
R-squared	0.974			
Adj. R-Squared	0.971			
F-stat	391.39			
Prob. F-stat	0.000***			
Root MSE	0.046			

Source: *** p<0.01.

Table 4 also presents several goodness-of-fit indicators, including the R-squared, Adjusted R-squared, F-statistic, and Root MSE. The R-squared value of 0.974 indicates that 97.4% of the variation in fossil fuel consumption can be explained by economic growth, trade openness, and urbanization. The remaining 2.6% is explained by other factors outside the model. As a corrected measure of explanatory power, the Adjusted R-squared is reported at 0.971, which is only slightly lower than the R-squared value. This suggests that the model maintains a strong explanatory capacity even after adjusting for the number of independent variables included in the regression. The F-statistic is 391.39 with a probability value of 0.000, indicating that all independent variables are jointly significant in explaining fossil fuel consumption. In other words, economic growth, trade openness, and urbanization simultaneously exert a meaningful influence on the dependent variable. Finally, the Root Mean Squared Error (Root MSE) is 0.046, which is relatively close to zero. This implies that the model has a low prediction error and performs well in fitting the observed data. Overall, these results suggest that the estimated model is statistically robust and suitable for interpretation.

3.2. Discussion

The estimation results show that economic growth has a positive and statistically significant effect on fossil fuel consumption in Indonesia. The contribution of economic growth to fossil fuel consumption is estimated at 1.2%. This finding confirms that economic expansion in Indonesia remains highly dependent on fossil-based energy. This mechanism can be understood by the fact that as economic output increases, production activities and the mobility of goods and services also expand, thereby increasing energy demand (Asafu-Adjaye et al., 2016). As illustrated in Figure 1, when economic growth remained relatively stable within the range of 4.9–5%, fossil fuel consumption also increased gradually. This result is consistent with the findings of Acheampong et al. (2021) and Shahbaz et al. (2022). According to Acheampong et al. (2021), in the context of developing countries, economic output tends to stimulate energy demand, yet such demand is often not fully matched by an adequate and efficient energy supply system, leading to a substantial increase in energy use. In other words, when economic expansion occurs without a corresponding improvement in energy availability or efficiency, an energy gap may emerge. Shahbaz et al. (2022) further argue that developing economies often face technological limitations, leaving

them with few alternatives other than maximizing the use of domestically available fossil energy resources. However, the broader challenge of energy use also depends heavily on the quality of human capital.

The urbanization variable is also found to have a positive and statistically significant effect on fossil fuel consumption in Indonesia. The estimated impact suggests that fossil fuel consumption increases by 3.7% due to urbanization. This finding indicates that urbanization plays a substantial role in shaping fossil energy demand. The result is in line with Shahbaz et al. (2017) and Ho et al. (2021), but differs from the findings of Degirmenci et al. (2025). According to Shahbaz et al. (2017), migration from rural to urban areas is largely driven by the better infrastructure and broader economic opportunities available in cities. Urban areas generally provide more adequate access to education, healthcare, and employment, which in turn attracts population inflows. As a consequence, this process increases demand for housing, transportation, and urban infrastructure. These changes inevitably lead to a significant rise in electricity and energy demand. To ensure sufficient electricity supply, governments often rely on rapid and readily available solutions, which in many developing countries still involve fossil-based energy sources. Meanwhile, Ho et al. (2021) emphasize that urbanization represents a form of modernization that stimulates social and economic transformation, both of which require large amounts of energy. Their study further notes that Indonesia has remained dependent on fossil energy (coal and natural gas) during certain stages of development.

Furthermore, trade openness exerts a positive and significant effect on fossil fuel consumption, with an estimated contribution of 0.5%. This finding is consistent with the studies of Koengkan & Fuinhas (2022) and Osei-Assibey Bonsu & Wang (2022), although it differs from the results reported by Shahbaz et al. (2014) and Pan et al. (2019). According to Koengkan & Fuinhas (2022), the relationship between trade openness and energy consumption can be explained by the expansion opportunities it creates for the industrial sector, which subsequently contributes to broader economic growth. As industrial expansion intensifies, investment also tends to increase, thereby generating additional energy demand. In the context of developing countries, meeting this rising energy demand often requires greater energy imports or increased dependence on conventional energy sources. Osei-Assibey Bonsu & Wang (2022) further argue that when domestic energy supply is insufficient to support trade-related economic activities, imports become one of the primary channels for maintaining energy availability.

4. Conclusion

This study aims to investigate the macroeconomic determinants of fossil fuel consumption in Indonesia over the period 1990–2024 by examining the roles of economic growth, urbanization, and trade openness. Based on a log-linear multiple regression model, the findings reveal that all explanatory variables have a positive and statistically significant effect on fossil fuel consumption. These results provide an

important signal that macroeconomic dynamics continue to drive the use of fossil-based energy in Indonesia.

Based on these findings, several important policy recommendations can be drawn. First, economic growth in Indonesia has largely been supported by the industrial, transportation, and service sectors, all of which remain heavily dependent on fossil fuels. Therefore, the government needs to allocate sufficient resources to ensure future energy availability while gradually promoting energy-efficient technologies to reduce dependence on fossil energy. Second, the government should strengthen and improve energy-related regulations in urban areas by encouraging the adoption of renewable energy as an alternative source of energy. In this way, urban energy demand can be met without excessive reliance on fossil fuels, while also supporting the achievement of sustainable urban development. Third, the government needs to promote environmentally oriented trade activities by encouraging export and import practices that prioritize energy-efficient and cleaner technologies. Such efforts are essential to reduce the economy's structural dependence on fossil fuels and to support a more sustainable development pathway.

This study has several limitations. First, the availability of detailed data on specific fossil fuel sources, such as coal and natural gas, is limited, which limits a more detailed analysis of energy consumption patterns. Second, the model includes only a limited number of macroeconomic variables, namely economic growth, urbanization, and trade openness. Other potentially relevant factors, including renewable energy development, energy prices, human capital, and globalization, are not explicitly considered. Third, the empirical approach relies on a relatively simple multiple regression framework, which may not fully capture the dynamic relationships between variables. Therefore, future research is encouraged to address these limitations by using more comprehensive datasets, incorporating a wider range of explanatory variables, and applying advanced econometric techniques, such as autoregressive distributed lag (ARDL) models, to better capture short- and long-term effects or using causality models to examine causal relationships.

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