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Analyzing the Effect of Population Density on Household Energy Consumption: A Case Study of Indonesian Provinces

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ABSTRACT

Indonesia's rapid population growth and urbanization have intensified concerns about the rising demand for energy, making it crucial to understand the relationship between population density and energy consumption for effective policymaking. This study utilizes the STIRPAT model with multiple estimation methods, including OLS, FE, RE, FGLS, and PCSE, to explore the relationship between household energy use and population density at the provincial level in Indonesia. The analysis is based on data from 2018 to 2022, focusing on household electricity and gas usage ratios as dependent variables. Independent variables include Gross Domestic Regional Product (GDRP) Per Capita, total population, population density, and the percentage of value added by GDRP. The results indicate a positive relationship between population density and household electricity and gas consumption during the study period. These findings emphasize the need for targeted and efficient energy policies to address the growing energy demand associated with population density trends.

Keywords: Electricity; Energy Consumption; Gas Consumption; Households; Population Density; STIRPAT

INTRODUCTION

Rapid urbanization, developing international population, and economic boom, in particular in advancing nations, multiplied humanity's starvation enabling energy to reach previously unheard-of tiers. However, the lack of right of entry to modern electricity is a problem, with nearly 10% of the arena's populace not having access to electricity (International Energy Agency, 2022). In addition, the current energy machine nevertheless is based heavily on fossil fuels, which in turn contributes drastically to the increase of greenhouse gases and different environmental troubles (Rahman & Vu, 2021). Therefore, the world is currently facing two major challenges, that is, the energy crisis and environmental pollution. With the growing realization of this dual challenge, the world is officially committed to providing affordable, sustainable, and accessible modern energy in Sustainable Development Goal (SDG) 7 to meet growing energy needs and combat environmental issues (Acheampong et al., 2017; World Bank, 2021).

Indonesia has experienced high economic growth along with rapid population growth (Kolinug & Winerungan, 2022; Runtunuwu & Kotib, 2021), resulting in a large increase in energy consumption. Real GDP has risen steadily at around 6-7% over the past few decades, while the nation's final energy demand increased 14-fold from the 1970s to the present (Middle East Research Institute, 2020). As the fourth largest population in the world, economic growth and population increase have contributed to an increase in household energy consumption in particular (Nejat et al., 2015). To date, Indonesia has been classified among upper-middle-income nations, a status that correlates with heightened levels of energy consumption, particularly in the realm of electricity (McNeil et al., 2019).

In developing countries such as Indonesia, energy is key to household welfare which drives economic growth and development (Hakam et al., 2022). The household sector contributed 14.8% of national energy consumption in 2018, 3.4% more than in 2012 (Riza, 2019). The most consumed energy types in the household sector are electricity and LPG (Rianawati et al., 2021). Energy access has improved in Indonesia in recent years. Nationally, the value of the electrification ratio in 2021 is 99.45% and 83.36% is dominated by the use of more environmentally friendly cooking fuels such as LPG (Hidayanto et al., 2021)

According to Muzayanah et al. (2022), they have investigated the relationship between population density and energy consumption in aggregate across provinces in Indonesia. As research in Indonesia has inadequate data on population density and consumption, this study analyzes the connection between energy usage and population density focusing on households in Indonesia. To date, empirical research that examines the relationship between population density and energy consumption in Indonesia with a focus on households is limited. Hence, as a contribution, this research aims to analyze the association between population density and energy consumption using comprehensive models including Linear regression with Driscoll-Kraay standard error (DK), Random Effect (RE), Pooled Least Squares (POLS), Fixed Effect (FE), and Feasible Generalized Least Squares (FGLS). These models are expected to get better and more comprehensive results.

LITERATURE REVIEW

A study by Sarkodie and Adom (2018) examined the drivers of aggregate power usage, fossil fuel, and the amount of electricity used in Kenya. The consequences showed that populace Kenya's urbanization and density decreased total energy consumption from fossil fuels such as gasoline, but had the other effect on electricity consumption.

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Research conducted by Rahman (2020), explains that economic growth and population density have a significant positive effect on energy consumption in both the short and long term. CO2 emissions are also positively and significantly affected by population density and energy consumption, and negatively affected by economic growth.

Research by Su (2011) shows different results. Using both semiparametric and parametric approaches, the study aims to explore the impact of population concentration, and freeway density, and consider the impact of traffic on residential gasoline use in US cities while controlling for household demographic and economic characteristics. As a result, households living in urban areas with higher freeway density, higher congestion levels, or lower population density consume more petrol. A study by Salim (2014) shows similar results that population and urbanization have a positive effect on non-renewable energy consumption, but population density hurts non-renewable energy consumption.

Another study conducted by Yao (2011) concluded that non-economic and non-technological factors have a significant impact on reducing energy consumption. Population density does not contribute to the reduction of energy consumption, but when combined with energy consumption density with spatial context together, the contribution is quite efficient.

Improvements in electrical energy efficiency can be used to avoid the expansion of existing fossil power plants to meet Indonesia's growing electricity demand. The results show that the appliances that can save the most electrical energy are lamps, TVs, refrigerators, and air conditioners. To avoid the construction of new power plants, the survey data was used to initiate an energy-saving program (Batih & Sorapipatana, 2016).

The results of a study conducted by Zhang and Lin (2012) showed that urbanization increases energy consumption and CO2 emissions in China. Therefore, this nevertheless wishes to be studied, especially in Indonesia, where the country's population is anticipated to remain within the coming years (Jones, 2015). In gas use models, higher household density leads to less gas use. Conversely, higher firm density tends to lead to more gas use (Caballero-Anthony et al., 2012). A study conducted by Boukarta & Berezowska-Azzag (2018) showed that an increase in household size is the first factor that reduces electricity and gas consumption, followed by house size, density, occupancy rate, and older households, while an increase in education level and appliance ownership increases gas and electricity consumption per capita.

RESEARCH METHOD

Model

Referring to the reference from Dietz & Rosa (1997) who modified the IPAT model into a model called STIRPAT. The STIRPAT model is a reformulated model from the IPAT model (Ehelich & Holdeen 1971). The IPAT model has limitations in that (1) it does now not allow the test of significance because a mathematical identity is IPAT; (2) every factor within the model includes an identical impact on the surroundings; and (3) cannot define elements which have a more effect on the surroundings. Consequently, Dietz & Rosa (1997) advanced the STIRPAT model to conquer the restrictions of the IPAT model. A fundamental characteristic of the STIRPAT version is its asymptotic design, which allows the model to analyze how changes in socio-economic conditions affect environmental degradation. The STIRPAT model not handiest presents simple statistics approximately environmental degradation but also can suggest factors that can be especially attentive to policy (York et al., 2003). The STIRPAT version may be written as follows:

$$I_{i,t} = aP_{i,t}^{b} A_{i,t}^{C} T_{i,t}^{d} e_{i,t}$$

Inside the model above, a is the constant term, at the same time as b, c, and d are the terms. The environmental effect elasticities are P, A, and T, respectively. The object of analysis is denoted by the subscript i, while the variable e displays the error term, as an example in this observe is the province. After taking the logarithmic form, the STIRPAT model can be written as follows:

$$\text{In}I = a + b(\text{In}P) + c(\text{In}A) + d(\text{In}T) + e$$

with P indicating population, and a observed by GDRP per capita. For T, Bongaarts (1991) observed that variations in economic structure are reflected in variations in energy and emission intensity. Thus, Martínez-Zarzoso & Maruotti (2011), used industry share in GDP and energy intensity.

According to York et al. (2003), the STIRPAT model can amplify the model with the aid of including several factors into explicit T besides A and P. Liddle (2014) brought urban density variables into the expanded STIRPAT version. This study uses the STIRPAT version which is expanded by including a variable for population density (denoted by using DEN). Gunningham (2013) argues that the use of the demographic factor (POP) serves as a gauge issue due to adjustments in populace increase having a fraction impact on the boom of electricity utilization. Consequently, if this research desires to correctly decide the effect of population growth on energy usage, it needs to include oblique effects of populace tactics, for example, populace density (Liddle, 2014); (Gunningham, 2013). Density and industrialization also have a significant impact on energy use. Industrialization is often included as an additional variable in STIRPAT models (Martínez-Zarzoso & Maruotti, 2011; Poumanyvong & Kaneko, 2010; Chuanguo Zhang, 2012). Investigating how industrialization affects overall energy use requires a formula that considers several variables, so the formula can be divided into two:

$$ELC_{\text{it}} = \beta_0 + \beta_1(InGDRP_{\text{it}}) + \beta_2(InDEN_{\text{it}}) + \beta_3(MIS_{\text{it}}) + e_{\text{it}}$$
$$LNG_{\text{it}} = a_0 + a_1(\text{In}GDRP_{\text{it}}) + a_2(\text{In}POP_{\text{it}}) + a_3(\text{MIS}_{\text{it}}) + e_{\text{it}}$$

Where MIS and DEN represent density and industrialization, respectively, and the proxy for energy intensity (ELC) uses ratio electrification separated with the aid of GDRP. Similar to Zhang and Lin (2012), shows individual impacts, reflecting differences between countries in terms of environmental regulations and benefits of energy resources. The time effect is represented by Y, which controls for time-varying factors. Province and year are denoted by the subscripts i and t, respectively.

Methodology

This research uses five distinctive estimation techniques: Pooled Least Squares (POLS) fixed effect (FE) Random effect (RE) feasible generalized least squares (FGLS), and Panel-corrected standard errors (PCSE). The estimation results and comparison of results can be seen in Table (3). This estimate is used to examine how population density affects energy intake in households, with the dependent variables namely the electrification ratio and the ratio of gas users in households. The first methodology, POLS is used to achieve the simplest estimates. However, POLS is unable to overcome the problem of heterogeneity between provinces. Some statistical analyses were also performed to demonstrate some of the problems with FE estimation, such as panel tests for autocorrelation (Zax, 2019; Ye et al., 2015), heteroscedastic tests (Winkelmann, 2008), and cross-sectional dependency checks using the Pesaran method (Pesaran et al., 2004). The outcome shows that each model in the FE estimation verifies the existence of this problem. As a result, although the results are not biased, the FE estimation is not effective. To overcome this problem, FGLS estimation is considered.

The number of cross sections or time dimensions (t) in this study is not equal to N. is more than the time series. Therefore, to solve this problem, PCSE estimation is used. The results of this estimation will be discussed further in the analysis section.

Data
This research uses panel data from 34 provinces in Indonesia. The data used are energy consumption, GDP per capita, population, population density, and manufacturing industry share obtained from the Central Bureau of Statistics. Energy consumption is measured from the Electrification Ratio which is the ratio of the number of electricity customers to total households and gas consumption from the ratio of gas use in households. Detailed descriptions of the factors and information sources utilized in this research can be seen in Table 1.

Table 1. Definitions of Variables Used in This Research and Their Sources

Variable	Definition	Unit	Source
Electrification Ratio	Comparison between the number of customers with electricity and the total number of households	Ratio	Central Bureau of Statistics, Statistic PLN
Household Gas Use Ratio	Comparison between the number of households using gas to the total number of households	Ratio	Central Bureau of Statistics, Statistic PLN
Gross Regional Domestic Product	GRDP total real constant income 2010	Billions of Rupiah	Central Bureau of Statistics
Population Density	Number of population per KM²	People	Central Bureau of Statistics
Population	The total population of each province	Thousand people	Central Bureau of Statistics
Value Added Industry Share (IND)/Share of Industry	Proportion of industrial added value to GRDP of each province in Indonesia	Proportion	Central Bureau of Statistics

RESULTS

Analysis Descriptive
Table 2. Descriptive Statistics (N =170)

Variable	Min	Max	Mean	Std. Dev.
ELC	62.07	100	97.21	5.17
LPG	0.75	98.23	71.63	30.29
GRDP	9.42	12.12	10.51	0.54
POP	6.53	10.81	8.40	1.01
DEN	2.12	9.68	4.90	1.58
MIS	1.17	43.42	16.27	11.24

Note: Std.Dev = Standard Deviation.

Based on Table 2, the outcomes of the descriptive statistic output on the variable Electrification Ratio (ELC) which is used as the dependent variable of this research has 62.07 as the minimum and 100 as the maximum, and the variable gas use in households (LNG) ranges from a minimum of 0.75 to a maximum of 98.23. Electrification ratio variable (ELC) with an average value (mean) of 97.20. This shows that on average the research sample has an electrification ratio level that is not far from the maximum value. This means that people in Indonesia have quite high electrification. The standard deviation with a value of 5.17 indicates that data fluctuations in the electrification ratio in the research period are low, this is because the average value exceeds the value of the standard deviation.

The gas use variable (LPG) has a minimum value of 0.75 and a maximum value of 98.23. The Variable gas use ratio (LPG) has an average (mean) value of 71.62. This shows that on average the research sample has a user level that is quite far from the maximum value. It can be seen from this that gas usage among Indonesians is not very widespread. The standard deviation with a value of 30.26 shows that data fluctuations in the ratio of gas use (LPG) are very high, this is because the average value exceeds the value of the standard deviation.

9.46 is the lowest number of the Variable Gross Regional Domestic Product (GRDP), and 12.12 is the highest. The variable GRDP has an average value of 10.51. This shows that on average the research sample has a GRDP level that is quite far from the maximum value. This means that income in countries in Indonesia is not too much. GRDP has 0.54 as the standard deviation, which shows that data fluctuations from the GRDP variable are low due to the average value is higher more than the standard deviation.

Variable Population (POP) has 6.53 as the lowest figure and 10.81 as the highest. The variable POP has an average value of 8.40. This shows that the average research sample has a population level that is quite far from the maximum value. This means that the population of countries in Indonesia is not too large. The population has 1.01 as the standard deviation, which shows that data fluctuations from the Population variable are low due to the average value being more than the standard deviation.

Variable Population Density (DEN) has 2.12 as the least and 9.68 as the maximum. The variable DEN has an average value of 4.89. This shows that on average the research sample has a user level that is far from the maximum value. This means that the population density in Indonesian countries is not too dense. Population density has 1.58 as the standard deviation, which shows that data fluctuations from the DEN variable are low due to the average value being higher more than the standard deviation.

The Variable Manufacturing industrial sector (MIS) has between a minimum of 0.16 and a high of 3.77. The variable MIS has an average value of 2.50. This shows that on average the research sample has a user level that is far from the maximum value. This means that the population density in Indonesian countries is not too high. MIS has a 0.83 standard deviation value, which shows that data fluctuations from the Manufacturing industrial sector variable are low due to the average value being higher than the variability.

Result Model

This study aims to determine how population density can affect energy consumption in the household. Results with the dependent variable of electrification are presented in Table 3, and LPG estimation results are in Table 4. The estimation results show that all variables are significant at the 1% level on both the dependent variables, except the Industry variable. In addition, all variables have a positive effect on Electrification and LPG in Indonesia.

Table 3. Result Model: Dependents Variable is ELC

Variables	(1) OLS	(2) FE	(3) RE	(4) FGLS	(5) PCSE
lnDEN	0.671***	1.683	0.680**	0.671***	0.671***
	(0.247)	(7.914)	(0.325)	(0.244)	(0.159)
lnGRDP	1.984***	4.781	1.995**	1.984***	1.984***
	(0.749)	(8.911)	(0.983)	(0.741)	(0.227)
MIS	0.0396	-0.304	0.0340	0.0396	0.0396***
	(0.0372)	(0.306)	(0.0486)	(0.0368)	(0.00845)
Constant	72.43***	43.68	72.36***	72.43***	72.43***
	(7.781)	(113.9)	(10.21)	(7.689)	(3.898)
N	170	170	170	170	170
R^2	0.121	0.008			0.121

Note: Standard errors in parentheses *p<0.10, **p<0.05, ***p<0.01

Table 4. Result Model: Dependents Variable is LPG

Variables	(1) OLS	(2) FE	(3) RE	(4) FGLS	(5) PCSE
lnPOP	10.38***	44.92***	19.20***	10.38***	10.38***
	(2.341)	(8.811)	(4.498)	(2.314)	(0.214)
lnGRDP	18.65***	43.40***	34.89***	18.65***	18.65***
	(4.231)	(7.108)	(5.973)	(4.181)	(0.873)
MIS	-0.0552	-0.448*	-0.313	-0.0552	-0.0552
	(0.226)	(0.262)	(0.239)	(0.223)	(0.0565)
_cons	-210.5***	-754.2***	-451.0***	-210.5***	-210.5***
	(50.37)	(107.7)	(75.94)	(49.77)	(10.03)
N	170	170	170	170	170
R^2	0.217	0.328			0.217

Note: Standard errors in parentheses *p<0.10, **p<0.05, ***p<0.01

The results show that an A one percent increase in population density will result in electrification by 0.671%. The GRDP estimation results show that it has a favorable and noteworthy of 1% on electrification. This demonstrates that an increase in GRDP of 1% will increase electrification by 1.984%. The estimation results for Industry (MIS) show that it has an important and favorable of 1% on electrification. This demonstrates that an increase in industry by 1% will increase electrification by 0.039%.

The Population (POP) estimation results show that it has a positive and significant effect of 1% on LPG. This shows that an increase in POP of 1% will increase LPG by 10.38%. The GRDP estimation results show that it has a positive and significant effect of 1% on Gas Consumption. This shows that an increase in GRDP of 1% will increase LPG by 18.65%. The estimation results for industry (MIS) show that industry has a negative and insignificant on LPG.

DISCUSSION

This study shows the density of the population has a positive and significant effect on electrification and LPG. The results of the study are in line with previous research by Muzayanah et al. (2022). Rahman's (2020b) research is also in line with this study which discovered that the density of the population has a considerable and remarkable influence on electricity usage. Similarly, population density across the country has both long-run and short-run positive impacts on electricity consumption. Additionally, these findings are consistent with earlier research by Sarkodie & Adom (2018) and Mindali et al. (2004), which found that population density has a favorable effect on electricity consumption. Research conducted by Liu et al. (2021) also found that the effect of population density on electrification is significant and positive, indicating that an increase in population density leads to an increase in electrification. In addition, a report from the National Energy Board also supports this result, that the best ratio of electricity usage to total energy consumption is found in Indonesia (Outlook, 2019).

The rise in the use of energy, especially, may be precipitated by growth in residing requirements for the center elegance earnings institution, with month-to-month profits between IDR 1.2 million to IDR 6 million (Mcneil et al., 2019). The middle magnificence in Indonesia has grown unexpectedly and has a roughly 10% yearly growth rate. Stated differently, one in five Indonesians is from the middle class (World Bank, 2019). This rationalization helps research performed by way of (Sarkodie & Adom, 2018), which states that better income will have a terrible effect on energy consumption. Case observed in Indonesia, the speedy economic increase may also cause an increase in call for fuel consumption (Akhmad & Amir, 2018).

Variables in this study are all statistically significant for electrification. This shows that both estimates with the welfare variable measured using GRDP affect energy consumption positively and significantly. Findings in Tables 3 and 4 show that a 1% increase in GRDP will increase electricity and gas consumption by 1.159% and 10.051%, respectively. These results indicate that an increase in GRDP will have a positive impact on energy consumption. Similar to Huang et al. (2008) who found that there is a good connection between energy use and GDP growth in nations with lower per capita incomes (Rahman, 2020) also stated the same conclusion regarding the effective elasticity between India's rising GDP and energy usage. The industry is also statistically significant in the estimation, indicating that the industrial sector is indeed highly dependent on energy use.

Results on household gas usage ratio. Table 4 suggests that the amount of gas consumed increases with population density. but, the pliability of electrification is more than the usage of gas. However, the elasticity of electrification is greater than the use of gas. The results show that increasing population density increases gas use by 5.55%. These results are consistent with studies carried out by Boukarta and Berezowska-Azzag (2018) stating that density also has a favorable and noteworthy impact on gas consumption. Interestingly, these results contradict studies carried out by Muzayanah et al. (2022) which state that household gas consumption per capita in urban areas has a very significant and negative direct impact, which shows that the decline in household gas consumption per capita in urban areas in local cities led to an increase in household per capita consumption of liquefied gas in urban areas.

This result may be contrary to the opinion that structural transformation will permit a country to transport from an eco-friendly agricultural area to an extremely polluting commercial zone and at a certain factor, it is going to transfer lower return to a tertiary area with low pollution levels (Adebayo et al., 2023). This contradictory cause can be due to reliance on total energy consumption derived from fossil fuels (Adebayo et al., 2023). Conclusions showing that density is an important factor in reducing energy consumption are contradictory and still controversial in the scientific literature (Gunningham, 2013).

CONCLUSION

This research looks into the relationship between the density of the population and electricity utilization in Indonesia with the proxies of the family electrification ratio and household gas consumption ratio. Using the STIRPAT model with OLS, FE, RE, FGLS, and PCSE estimation methods, this research employs panel data to obtain more robust coefficients. therefore, we can efficiently locate the causal consequences of energy use and population density. The research reveals a significant favorable relationship between population density and electrification, as well as a substantial impact on gas consumption in Indonesia. Policy recommendations include prioritizing infrastructure development, implementing energy efficiency programs in densely populated areas, integrating energy considerations into urban planning, diversifying energy sources with a focus on renewables, and fostering policy flexibility to adapt to changing patterns. Collaboration with stakeholders, regional considerations, and ongoing evaluations are crucial for successful implementation.

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DECLARATION OF CONFLICTING INTERESTS
The author(s) declared no potential conflicts of interest.

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