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Mobility of non-permanent workers and energy consumption in Indonesia

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ABSTRACT

Expensive land in urban centers encourages workers to migrate to the suburbs, creating worker mobility that increases energy consumption and worsens environmental quality. Therefore, understanding the relationship between worker mobility and energy consumption is crucial. This study evaluates the impact of worker mobility categorized as commuter and circular on energy consumption in Indonesia. We used the Extended Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model with instrumental variables (IV) on panel data from 33 provinces during the 2013–2018 period. The results show that commuter workers do not significantly affect total energy and fuel consumption, but significantly increase electricity consumption. Conversely, circular workers contribute significantly to increased total energy, fuel, and electricity consumption. Other impacts include decreased health and disruption to social life, despite the economic benefits. This study contributes to the literature on labor and energy in developing countries, particularly regarding the aspect of non-permanent workers. These findings are also relevant as a basis for formulating sustainable development policies that consider economic, social, and environmental aspects in a balanced manner.

1. Introduction

Indonesia is one of the countries that still adheres to a monocentric urban system or is centered on one point. An example is the province of DKI Jakarta, more precisely on Jalan Sudirman, Gatot Subroto, and Thamrin which are the centers of business and government. This type of city model causes land prices to become expensive so that urban sprawl occurs in suburban areas, such as Bekasi and Tangerang which are affected by the expansion of Jakarta. As a result, the travel distance and average worker salary have increased (Abozeid & AboElatta, 2021). This phenomenon is one of the driving factors for increasing energy consumption in Indonesia. In fact, the global energy market began to be depressed in 2021 due to the economic recovery being too fast and the emergence of the COVID-19 pandemic. However, the climax of this energy crisis occurred after Russia's invasion of Ukraine in February 2022. The prices of natural gas and electricity soared in the market, causing inflation to soar, increasing poverty rates and slowing economic growth, even potentially experiencing a recession (IEA, 2022).

As one of the oil importing countries, Indonesia needs to be aware of the crisis that is happening. This is because it can have a negative impact on energy prices which can have an impact on the economy. Report from Ministry of Energy and Mineral Resources (2024) shows fuel and electricity are the energy pillars used by the community from year to year. Meanwhile, the sector that uses the

most energy from 2013 to 2018 is the transportation sector followed by the industrial and household sectors. This sector is the reason why fuel is the type of energy with the highest consumption rate in Indonesia. If worker mobility is not controlled, the increase in energy consumption will continue to increase due to the increase in the transportation and electricity sectors. Not only that, environmental pollution as a result of energy use will also get worse. Based on research conducted by Crow & Millot (2020) there is a decrease in fuel and electricity at the workplace when worker mobility decreases. However, there is an increase in electricity in residential areas as a result of the change in work location. Other research related to the impact of worker mobility on fuel energy consumption is also studied by Noussan & Jarre (2021) and concluded that increasing the number of workers mobilizing will increase the use of transportation which will have an impact on increasing fuel prices.

Various literature related to energy consumption has been done in various parts of the world. Starting from the relationship between urban sprawl and energy consumption (Navamuel et al., 2018), the relationship between urbanization, industrialization and energy consumption (Ali, 2021), the relationship between population density and energy consumption (Muzayanah et al., 2022). In Indonesia, this relationship has also been studied by Subanti et al (2021); Sulistiyaningsih et al (2025); Jafari et al (2012) and Shahbaz et al (2013). However, there has been no econometric study that directly considers the impact of worker mobility living in sprawl areas on energy consumption. Previous studies have used mathematical calculations to calculate the impact of worker mobility. Meanwhile, research with inferential analysis focuses more on the relationship between urban sprawl and demand for transportation or the relationship between transportation and energy consumption. In fact, BPS noted that the majority of workers who mobilize drive private or official vehicles. Therefore, it is important to consider the worker mobility factor because there is energy generated from the activities carried out by workers.

Therefore, a study is needed that aims to analyze the relationship between non-permanent worker mobility and energy consumption in Indonesia and how it impacts the economy. The contribution of the study is to analyze and determine policies related to non-permanent worker mobility in Indonesia. This research has novelty related to the econometric method which in its calculations considers the impact of the mobility of workers living in sprawl areas directly on energy consumption.

2. Literature Review

Bid Rent Theory and Monocentric Land Use Theory are two key conceptual frameworks in urban economics used to explain the spatial structure and dynamics of land use in urban areas. They are interrelated and provide insight into how location and distance from the city center influence land values, location preferences, and the distribution patterns of economic and social activities. Figure 1. Bid Rents and Monocentric Land Useillustrates the Bid Rents and Monocentric Land Use Theory which shows that land prices become more expensive as they approach the city center. The sector in this area is an office center that is willing to pay a high price in the hope of reducing transportation costs. This is because the cost of traveling using streetcars to work is relatively lower compared to transportation to exchange information between companies. Companies ultimately prefer to pay additional salaries to workers rather than increasing transportation costs so that workers move away from the center and encourage worker mobility.

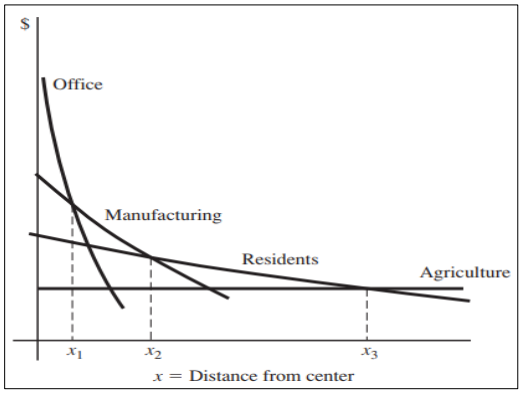

Figure 1. Bid Rents and Monocentric Land Use

According to Schettkat (1997) labor mobility can be in the form of movement from one job to another, from one employer to another, from one industry to another, from one region to another, from

working to being unemployed, or from working to not being in the labor force. Meanwhile, based on the Central Bureau Statistics classification, there are two types of labor mobility in Indonesia, namely spatial labor mobility and non-spatial labor mobility. Non-spatial labor is the movement from one worker to another job, either according to their sector or their employment status (Badan Pusat Statistik, 2020). Meanwhile, spatial labor mobility occurs when there is physical movement. This type of mobility is divided into two, namely permanent and non-permanent mobility. The difference can be seen from the dimensions of time and purpose. It is said to be permanent if workers move to another place with the aim of settling for more than or equal to six months. Apart from that, mobility is said to be non-permanent mobility. Non-permanent mobility is divided into commuter mobility and circular mobility.

Commuter workers are people who travel regularly for the purpose of working, going and returning home every day between their residence and workplace in different districts/cities. Meanwhile, circular workers are people who travel regularly for the purpose of working, going and returning home every week or every month (less than six months) between their residence and workplace in different districts/cities (Badan Pusat Statistik, 2020). This type of mobility is considered as one way to maximize family income with less risk. High worker mobility indicates that there is economic activity in a country. However, there are side effects that are produced, namely in the form of emissions released as a result of energy use. Based on research conducted by Crow & Millot (2020) argued labor market data and commuter trends, an increase in commuters over a week will increase fuel consumption in the transportation sector and increase electricity consumption in the workplace, but reduce electricity consumption in the residential area. However, the study found that over a year, the aggregate energy consumption reduction from the decrease in commuters is still four times greater than the increase in energy in the residential area. Moreover, Noussan & Jarre (2021) also found similar results in Lombardy, Italy. 26.5% of daily trips are work-related and the majority of commuters use private cars to work and take a large proportion of energy consumption.

However, most studies focus more on demographic and economic factors in conducting energy consumption analysis. An example is the study by Sarkodie & Adom (2018) that shows if the population density also influences energy consumption through energy decrease thoroughly and the fuel oil, but not with the electricity in Kenya. Nayan et al (2013) stated GDP significantly affects energy consumption, but energy consumption does not significantly affect GDP. This statement is further strengthened by Wang et al (2023) revealed that the growth of GRDP per capita indicates higher public consumption. High-income households will buy larger homes. This encourages the need for more lighting and equipment so that electricity consumption increases, especially in urban areas. GDP is closely related to industrial activity. When industrial activity increases, there is an increase in energy in the manufacturing sector compared to the agricultural sector (Sadorsky, 2014). This research was then further developed by Li & Lin (2015) which takes into account the economic level of a country. The results obtained are that in middle-/low-income and high-income countries, industrialization reduces energy consumption. Meanwhile, in low-income and middle-/high-income countries, industrialization increases energy consumption, but not significantly.

3. Method

The model on the control variables used is the STIRPAT framework developed from the IPAT model (I=PAT) to describe the impact of economic activities on the environment. The model was first developed by Ehrlich & Holdren (1971). The impact on the environment is usually described by energy use or CO2 emissions, which are symbolized by I. There are three factors that determine environmental quality, namely population size (P), affluence (A), and technology or impact per unit of economic activity (T). Considering that one of the advantages of the STIRPAT model is that it is a model that can be expanded by adding variables other than variables A and P to describe T (York et al., 2003), This study considers the impact of commuter and circular workers. Because the study aims to see the effect of worker mobility on energy consumption which is divided into total energy consumption, fuel energy consumption, and electricity energy consumption, the equations are separated into equations (1), (2), and (3). Based on these equation, the study develop in 3 models with the different dependent variables for each model.

$$lnTotal\_Energy_{i,t} = a_0 + a_1\, Commuter\_Worker_{i,t} + a_2\, Circular\_Worker_{i,t} + a_3\, lnDensity_{i,t} + a_4\, lnPDRB\_Capita_{i,t} + a_5\, lnIndustrialization\_Level_{i,t} + e_{i,t} \quad (1)$$

$$lnFuel\_Oil_{i,t} = \beta_0 + \beta_1\, Commuter\_Worker_{i,t} + \beta_2\, Circular\_Worker_{i,t} + \beta_3\, lnDensity_{i,t} + \beta_4\, lnPDRB\_Capita_{i,t} + \beta_5\, lnIndustrialization\_Level + e_{i,t} \quad (2)$$

$$lnElectricity_{i,t} = \gamma_0 + \gamma_1\, Commuter\_Worker_{i,t} + \gamma_2\, Circular\_Worker_{i,t} + \gamma_3\, lnDensity_{i,t} + \gamma_4\, lnPDRB\_Chapter_{i,t} + \gamma_5\, lnIndustrialization\_Level_{i,t} + e_{i,t} \quad (3)$$

Where model 1 is $lnTotal\_Energy$ is the total consumption from Total energy, fuel, and electricity for each province in Indonesia, model 2 is $lnFuel\_Oil$ is the the consumption of fuel consumed by all economic sectors and is included in the oil classification with a scope of light and heavy fuels, in the form of avgas, avtur, MDF, fuel oil, gasoline, diesel oil, and kerosene with units equivalent to barrels of oil (SBM) for one year, and model 3 $lnElectricity$ is the Per capita electricity consumption is the consumption of electrical energy consumed by all economic sectors originating from PLN in units of oil barrel equivalent (SBM) for one year. Table 1 shows the definition of variables used in the study.

Table 1. The Definition of Variables

Variable	Definition	Source
Energy Consumption	Total energy, fuel, and electricity for each province in Indonesia	Ministry of Energy and Mineral Resoures (KSEDM)
Fuel Oil Consumption	Fuel consumption is the consumption of fuel consumed by all economic sectors and is included in the oil classification with a scope of light and heavy fuels, in the form of avgas, avtur, MDF, fuel oil, gasoline, diesel oil, and kerosene with units equivalent to barrels of oil (SBM) for one year.	Ministry of Energy and Mineral Resoures (KSEDM)
Electricity Consumption	Per capita electricity consumption is the consumption of electrical energy consumed by all economic sectors originating from PLN in units of oil barrel equivalent (SBM) for one year.	Ministry of Energy and Mineral Resoures (KSEDM)
Commuter Worker	Workers who commute to work in a different district/city from their place of residence and will be counted as workers in the province of work	Central Bureau of Statistics
Circular Worker	Workers who commute to work in a different district/city from their place of residence and then return every week or every month (less than six months) and will be counted as workers in the province of work	Central Bureau of Statistics
Population Density	Population per km^2 for each province in Indonesia	Central Bureau of Statistics
PDRB/capita	Real GRDP per individual for each province in Indonesia	Central Bureau of Statistics
Industrialization Level	The value of the industrialization rate is described by the ratio of secondary industry to primary industry for each province in Indonesia	Central Bureau of Statistics

Source: BPS and KSEDM

In order to find the best method, various methods have been carried out in this study. First, regression using the pooled ordinary least squares (POLS) method. However, with the heterogeneity between provinces, the results obtained are biased. In order to overcome this problem, a fixed effects model (FEM) regression was carried out by adding individual effects (Hayat et al., 2023). Then, the third model tested was the random effects model (REM). Based on the test results using the Lagrange Multiplier and Hausman tests, it was concluded that FEM was the best model for this study. However, when the autocorrelation panel test was carried out using the Wooldridge test, an autocorrelation problem was found. Then, to confirm the existence of a heteroscedasticity problem, the Greene Likelihood Ratio Panel Heteroscedasticity Test was carried out and a heteroscedasticity problem was

also found. Finally, the Pesaran cross-sectional dependence test was carried out which showed a cross-sectional dependence problem (Baltagi, 2005).

To solve the three problems that occur, FGLS or Feasible Generalized Least Squares estimation is carried out. However, because the number of cross-sectional dimensions or provinces is greater than the time dimension or years 2013-2018, FGLS cannot be relied on because the standard error is likely to be underestimated then the Panel-Corrected Standard Error Estimation (PCSE) is used (Khasanah & Kurniawan, 2024). However, because the worker mobility variable is believed to be endogenous and there is reverse causality, the study finally used the IV dynamic panel method with lags from commuter and circular workers as instrument variables to ensure the exogeneity of the regressor (Baltagi, 2005). Then, the F-stat first-stage rule was also carried out which showed that the instrument variable in the form of a lag from the independent variable was a strong instrument. By considering all the problems that arise, it can be concluded that the method to be used in this study is the IV method.

4. Results and Discussion

Before conducting a regression analysis, it is important to understand the basic characteristics of the data used in this study. Therefore, descriptive statistics are needed to provide an overview of the distribution of values for each variable analyzed. Table 2 describes descriptive statistics for all variables used in this study. Because the analysis unit is a province totaling 33 and from 2013 to 2018, the number of observations studied is 198. The provinces used do not include North Kalimantan considering the limited data obtained. In this study, there are no missing values so that the data used is complete.

Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max	Unit
Total energy consumption	198	13.498	26.005	0.723	227.215	Million SBM
Fuel oil consumption	198	9.676	22.375	0.571	215.669	Million SBM
Electricity consumption	198	3.822	6.561	0.122	29.858	Million SBM
Density	198	735.057	2634.118	8.537	15804.25	People/km^2
PDRB/capita	198	37.657	29.472	10.397	165.769	Thousand Rupiahs
Industrialization level	198	3.981	15.592	0.219	101.761	Proportion
Commuter worker	198	3.028	5.649	0	28.3	Percentage
Circular worker	198	3.023	6.816	0.1	35.3	Percentage

Source: data processed

Figure 2 shows between fuel and electricity consumption, the average fuel consumption is higher, indicating that the fuel consumption rate is greater than electricity in Indonesia. Based on its type, fuel is in the number one position as the most consumed energy by the community and industry. In addition, the standard deviation of fuel is also higher than electricity, indicating that the amount of fuel consumed is more varied. The same thing also happens to commuter and circular workers. Because development and standards of living in each region are different, there are areas with higher levels of worker mobility because workers want to improve their economy.

The four provinces that are often included in the top three provinces with the highest number of commuter and circular workers are located on the island of Java, namely West Java, DKI Jakarta, Central Java, and East Java. This indicates that the economy is still centered on the island of Java compared to other islands. However, DKI Jakarta has never been in the top three with the largest number of circular workers. The reason could be because the cost of living in Jakarta tends to be expensive and access to easy and cheap public transportation causes workers to prefer to become commuter workers. According to the formulation of the problem and objectives, the study will examine the relationship between independent variables, namely worker mobility described by commuter and circular workers with dependent variables, namely total energy consumption, fuel, and

electricity. Figure 2 shows a positive correlation between commuter workers and circular workers with total energy consumption, fuel consumption, and electricity consumption. This indicates that if there is an increase in commuter or circular workers, there will also be an increase in total energy consumption, fuel, and electricity.

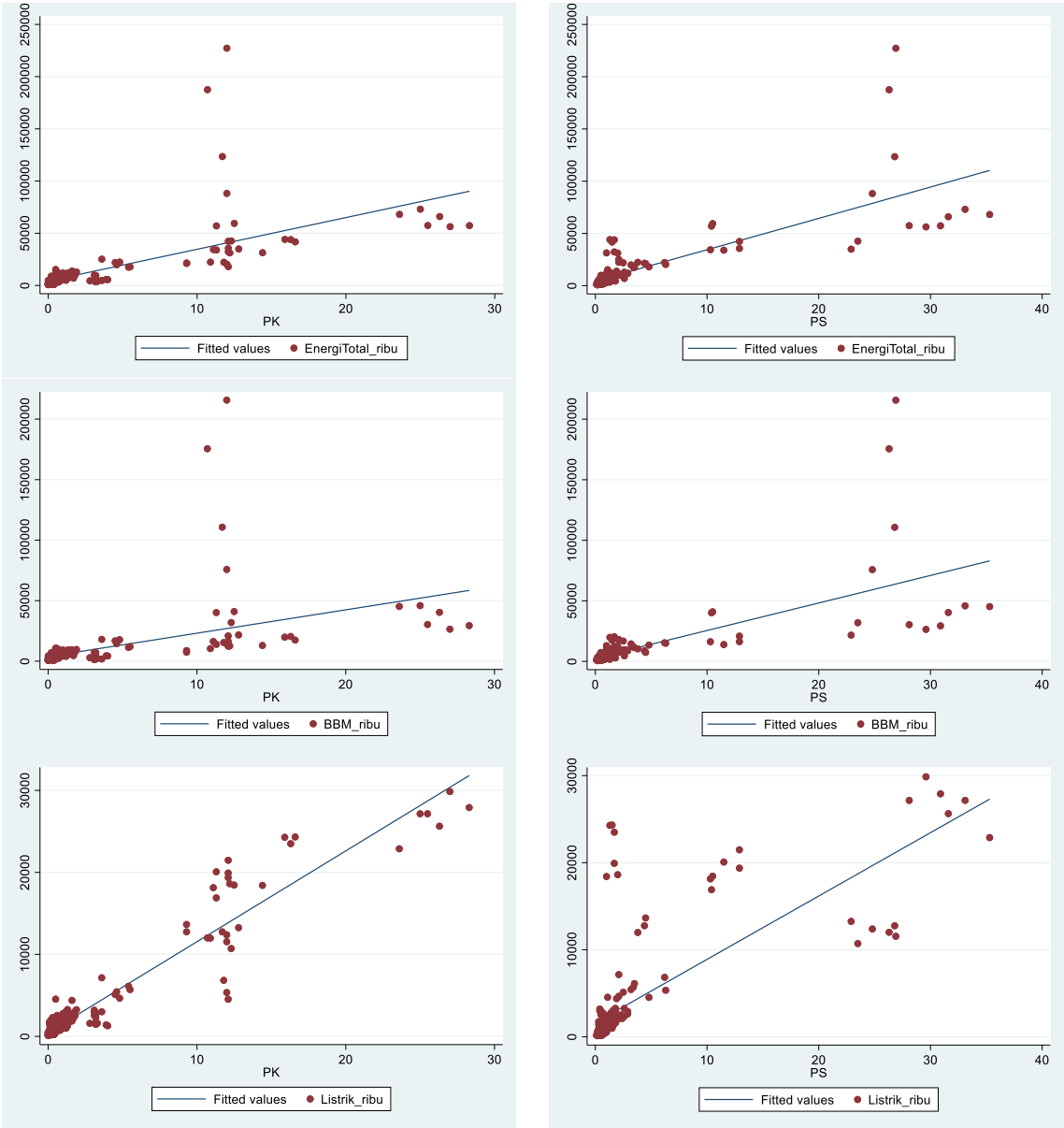

Figure 2. Scatter Plot Graph of the Relationship between Worker Mobility and Energy Consumption

As explained in the research method, the analysis will only be based on the Panel IV method which is the best method in this study. Based on the regression results, the type of worker mobility will have different impacts on the three types of consumption. Because the variable instrument used is a lag of the independent variable, the number of observations is reduced by one for each province. As a result, the total number of observations in this study which initially amounted to 198 became 165. The first result obtained is a 1% increase in commuter and circular workers who work or go to province X for work will increase 6.53% and 5.1% of electricity consumption in the province. This result is consistent with the scatter plot graph in Figure 1 which illustrates that worker mobility has a directional relationship with electricity consumption. Meanwhile, different results were obtained for total energy consumption and fuel energy.

The results of Table 3 and 6 shows that commuter workers do not have a significant effect on the two types of energy consumption. In addition, the results of the scatter plot graph in Figure 1 are also inconsistent with this finding. Meanwhile, if circular workers who work or go to province X for work increase by 1%, it will significantly increase total energy consumption by 9.4% and fuel energy

consumption by 11.4% in the province. This positive directional relationship is also supported by the results of the scatter plot graph which both show a positive relationship with total energy consumption and fuel. All control variables, except the level of industrialization, significantly affect the three types of energy consumption. Increases in density and GRDP per capita significantly affect the increase in energy consumption.

The results of Table 3, 6, and 7 shows a 1% increase in population density will increase total energy, fuel, and electricity consumption by 0.296%, 0.241%, and 0.406%, respectively. This finding contradicts the efficiency that should be obtained in consuming energy if density increases. The results obtained are also inconsistent with Cartone et al (2021) and Sarkodie & Adom (2018) who argue that increasing density should decrease energy consumption. However, this result is in line with Muzayanah et al (2022) which both use Indonesia as a research object. GRDP per capita also has a significant impact on all three types of energy consumption. The study stated that if the increase in GRDP per capita by 1% will increase total energy consumption, fuel, and electricity by 0.603%, 0.502%, and 0.898% respectively. The results also confirm that the higher the GRDP, the higher the energy consumption used. This finding is in line with the findings of Nayan et al (2013) and Wang et al (2023) which concludes that GRDP per capita has a significant influence with a positive relationship with total energy consumption, fuel and electricity.

Table 3. Results of Total Energy Consumption

VARIABLES	(1) OLS	(2) RE	(3) FE	(4) PCSE	(5) Panel IV
Commuter_Worker	-0.00560	8.67e-05	-0.0121	-0.00560	-0.00378
	(0.0234)	(0.0208)	(0.0249)	(0.0119)	(0.0252)
Circular_Worker	0.0919***	0.0839***	0.0881***	0.0919***	0.0940***
	(0.0140)	(0.0154)	(0.0218)	(0.00926)	(0.0155)
lnDensity	0.303***	0.117*	0.127	0.303***	0.296***
	(0.0509)	(0.0703)	(0.0836)	(0.0183)	(0.0536)
lnPDRB_Capita	0.611***	-0.383**	-0.891***	0.611***	0.603***
	(0.105)	(0.162)	(0.208)	(0.0393)	(0.113)
lnIndustrialization_level	-0.0445	0.269**	0.0700	-0.0445*	-0.0490
	(0.0894)	(0.134)	(0.224)	(0.0257)	(0.0947)
Constanta	-2.003***	2.361***	4.074***	-2.003***	-1.971***
	(0.529)	(0.711)	(0.778)	(0.193)	(0.566)
Diagnostic Tools					
Observations	198	198	198	198	165
R-squared	0.719		0.200	0.719	0.728
Number of Province	33	33	33	33	33
Autocorrelation Test			F(1,32) = 74.416***		
CSD Test			CD = 8.393***		
Heteroscedasticity Test			126.83812***		

Noted: Standard errors in parentheses and *** p<0.01, ** p<0.05, * p<0.1

The analysis of the research is divided into two sectors, namely the transportation sector as seen from the increase in fuel prices in Table 6, and the electricity sector as seen from the consumption of electrical energy in Table 7. Transportation sector has two types of transportation options that can be used by workers to travel to work are private transportation and public transportation. One of the public transportation that is relied on by the community to work is the Commuter Line (KRL) which uses electricity to operate. Both types of worker mobility significantly affect the increase in electricity consumption with a positive relationship. This increase in electricity consumption has the potential to be driven by the increasing number of KRL passengers from year to year, resulting in an increase in the number of trips/days taken by KRL. Table 4 shows data related to the number of KRL passengers in Jabodetabek, Non-Jabodetabek (Java), and Sumatra and If it is compared to 2013, the number of commuter line passengers in 2018 increased by 1.954 times. With the increase in commuter line, the electricity used in the transportation sector has also increased as shown in Figure 3. Increased train passengers can reduce social problems such as traffic congestion and save travel distance. However,

challenges in public transportation in developing countries remain high, such as adequate service, arrival time, etc. Government policies that accommodate workers in using public transportation services are important for improving services and are a key factor in becoming a smart city.

Table 4. Number of Passengers and Commuter Line Trips

Year	Number of KRL Passengers	Trip/day
2013	216.010	-
2014	277.508	-
2015	325.945	881
2016	351.820	898
2017	393.268	926
2018	422.129	936

Source: KAI Commuter

According to the theory related to commuting costs, workers tend to minimize travel costs by trading off between wages and travel time (Cass & Faulconbridge, 2016). If workers have limited salaries, workers will prefer to use cheaper vehicles to work. This is also one of the reasons why when worker mobility increases, KRL will increase so that electricity consumption increases.

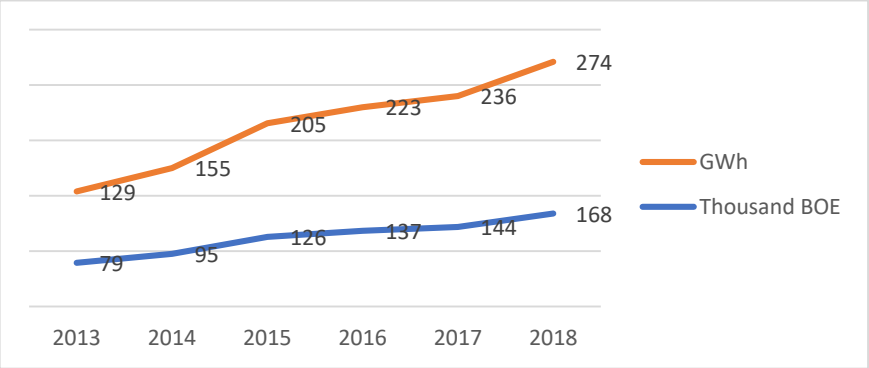

Figure 3. Electricity Consumption in the Transportation Sector

Contrary to previous research from Crow & Millot (2020) and Noussan & Jarre (2021) stated increasing commuter workers will increase fuel consumption. However, the conclusions obtained by the two researchers did not consider the existence of circular workers. Meanwhile, the results of this study state that the factors that significantly affect fuel and total energy are only circular workers, not commuter workers. The results are reinforced by the type of transportation chosen by workers based on travel time to the workplace in Table 5. Circular workers who rent a place to live around the workplace will make the travel time to work shorter. Based on the data, workers who spend less than an hour traveling are dominant in using private transportation compared to public transportation.

Table 5. Percentage Distribution of Workers' Travel Time by Type of Transportation Used in 2018

Traveling Time	Types of Transportation				Total
	Public	Altogether	Private	None	
≤ 30 minutes	19.9	20.7	30.4	82.4	29.7
30 – 60 minutes	38.5	42.8	46.6	8.5	45.0
61 – 120 minutes	32.3	24.1	19.0	2.9	20.4
> 120 minutes	9.4	12.4	4.0	6.2	4.9
Total	100	100	100	100	100

Source: BPS (2020)

This decision could occur because, apart from wages and travel time, one of the determining factors for the type of transportation chosen is the subjective well-being (SWB) of the worker, such as the quality of the trip, work flexibility, and the availability of transportation modes (Chatterjee et al., 2020). The faster the travel time, the cheaper the travel cost will be if using private transportation. Therefore, workers have greater utility to use private vehicles because they can maximize comfort by minimizing stress levels as an impact of using public transportation. Areas that implement the smart city concept have great opportunities to improve the quality and quantity of public transportation that is accessible, affordable, and punctual.

Electricity sector is not only from the transportation sector, increasing worker mobility will also increase the use of electrical energy in the province of destination. The difference with the transportation sector is that electrical energy is significantly affected by both types of worker mobility. For example, when workers do mobility either by commuting or circular to Jakarta, the electrical energy consumed in the province of work will increase to support operational activities. It is different from commuter workers who live in the same province as their workplace, circular workers will rent a 'second home' in the province. In this condition, circular workers have a main house that is far from the workplace so they choose to rent another place to live closer to their workplace. The electricity used in the household sector in the province will also increase. Because electricity and fuel are significantly influenced by circular workers, this type of worker mobility significantly drives total energy consumption as well as in Table 3. The results obtained are also supported by previous research from Crow & Millot (2020) stated that worker mobility will increase electricity consumption at the workplace by more than 20%. If workers work in a district/city that is different from the district/city where they live, then working outside the district/city will increase electricity consumption in the province where they work. This can happen because when working, workers need electricity to produce an output. However, the percentage of the impact that occurred in this study was smaller than the study (Crow & Millot, 2020).

Table 6. Results of Fuel Energy Consumption

Variables	(1) OLS	(2) RE	(3) FE	(4) PCSE	(5) Panel IV
Commuter_Worker	-0.0327	-2.82e-05	0.0216	-0.0327**	-0.0365
	(0.0248)	(0.0276)	(0.0338)	(0.0129)	(0.0267)
Circular_Worker	0.108***	0.0925***	0.137***	0.108***	0.114***
	(0.0149)	(0.0193)	(0.0295)	(0.0106)	(0.0164)
lnDensity	0.251***	0.0629	0.153	0.251***	0.241***
	(0.0540)	(0.0889)	(0.113)	(0.0307)	(0.0567)
lnPDRB_Capita	0.512***	-0.520***	-1.666***	0.512***	0.502***
	(0.111)	(0.200)	(0.282)	(0.0516)	(0.119)
lnIndustrialization_Level	-0.0345	0.230	0.138	-0.0345	-0.0314
	(0.0948)	(0.163)	(0.304)	(0.0362)	(0.100)
Constant	-1.671***	2.769***	6.071***	-1.671***	-1.626***
	(0.561)	(0.908)	(1.056)	(0.272)	(0.599)
Diagnostic Tools					
Observations	198	198	198	198	165
R-squared	0.637		0.637	0.637	0.649
Number of Province	33	33	33	33	33
Autocorrelation Test			F(1,32) = 46.517***		
CSD Test			CD = 4.280***		
Heteroscedasticity Test			122.29803***		

Noted: Standard errors in parentheses and *** p<0.01, ** p<0.05, * p<0.1

Even though it has a negative impact on energy consumption, worker mobility has a positive impact that can be felt directly and indirectly. Högberg et al (2007) highlighted that by doing mobility, workers get higher opportunities in a wider labor market with better potential to get what workers want and proper personal development. For specialized and highly educated workers, doing mobility can increase the chances of finding suitable jobs (Sandow & Westin, 2010). On the other hand, workers who are still looking for work or unemployed can also have a greater opportunity to meet the demand for the workforce needed. In addition, the benefits that can be felt by workers directly can be in the form of higher salaries and better abilities to climb the career ladder along with the increasing expansion of the search for workers (Sandow, 2011).

The higher income received by workers who mobilize also allows workers to contribute to the economy of their home region through local spending, such as the development of new housing infrastructure. In addition, the regional economy is also positively impacted by the development of new businesses in the area where workers live (Storey, 2010). For high skilled labor, being able to mobilize is indeed an advantage. As a result, workers will choose to work in areas with greater job

opportunities and salaries. The impact is that areas that are not city centers will be filled with low skilled labor. Another challenge faced by developing countries, and Indonesia in particular, is the high population density in economic centers and office districts. An example of a case that occurs in Indonesia is that high-skilled workers outside Java will come to Java, which is the center of the Indonesian economy, to get better jobs. As a result, low skilled labor will be more dominant outside Java.

Table 7. Results of Electricity Energy Consumption

VARIABLES	(1) OLS	(2) RE	(3) FE	(4) PCSE	(5) Panel IV
Commuter_Worker	0.0581**	0.0394**	-0.0184	0.0581***	0.0653**
	(0.0253)	(0.0196)	(0.0230)	(0.00480)	(0.0277)
Circular_Worker	0.0550***	0.0304**	-0.0291	0.0550***	0.0510***
	(0.0151)	(0.0150)	(0.0201)	(0.00271)	(0.0170)
lnDensity	0.416***	0.201***	0.0611	0.416***	0.406***
	(0.0550)	(0.0675)	(0.0772)	(0.0153)	(0.0589)
lnPDRB_Capita	0.896***	0.745***	1.007***	0.896***	0.898***
	(0.113)	(0.158)	(0.192)	(0.0254)	(0.124)
lnIndustrialization_Level	-0.111	0.227*	-0.0284	-0.111***	-0.121
	(0.0966)	(0.133)	(0.207)	(0.0186)	(0.104)
Constant	-5.150***	-3.423***	-3.304***	-5.150***	-5.101***
	(0.571)	(0.680)	(0.719)	(0.126)	(0.622)
Diagnostic Tools					
Observations	198	198	198	198	165
R-squared	0.786		0.786	0.786	0.783
Number of Province	33	33	33	33	33
Autocorrelation Test			F(1,32) = 1.175		
CSD Test			CD = 20.276***		
Heteroscedasticity Test			145.03861***		

Noted: Standard errors in parentheses and *** p<0.01, ** p<0.05, * p<0.1

The high mobility of workers to a location causes welfare and poverty to become concentrated in one area. Chetty et al (2014) stated areas with low sprawl levels have a higher chance of increasing the economic class in society. One of the reasons is because job opportunities are more available in areas with low sprawl. However, Högberg et al (2007) argues that workers can gain additional benefits from sprawl. As the monocentric land use theory, workers will move away from the city center and gain economic benefits with cheaper household expenditure, but better job opportunities in different locations. However, because it is far from the city center, the infrastructure obtained is also less when compared to the city center. For example, *Suroboyo Bus* is a type of public transportation provided by the government centered in Surabaya, but not all areas in East Java can enjoy this infrastructure. The distribution of the budget for infrastructure like this has positive and negative sides from the regional side. On the one hand, the government only needs to focus the budget on a few points. But, the downside is that infrastructure is uneven. Although it can reduce household expenditure, mobilization has a direct negative impact in the form of travel costs.

The productivity of a worker is also indirectly affected. Lyons & Chatterjee (2008) shows that increased travel time will lead to increased blood pressure, stress, neck problems, decreased mood, and decreased work performance. Worker mobility between districts/cities can also change the social status of workers and their families in a community. Several studies have shown that workers who mobilize tend to spend less time participating in community activities in their residential areas (Markey et al., 2015). Other research also states that the longer time workers spend working, the more they tend to spend time with their families or taking care of their households than participating in the community (Ezzedeen & Zikic, 2017). With less time to socialize with the community and additional income, mobility is seen as a potential trigger for tension in many communities (Walsh, 2012). The community has an unfounded idea regarding the income earned by workers who mobilize. With this idea, the expectations of community members regarding the contribution given by workers to the community are also affected (Hämäläinen & Böckerman, 2002). This will make it difficult for workers

and their families to build close relationships with the community where they live. The challenge for workers who are married and live far away from their families can increase their expenses.

The results obtained in the study are contradictory to the research Crow & Millot (2020) and Noussan & Jarre (2021) because both studies did not consider circular workers as part of worker mobility. The results obtained were that a 1% increase in commuter workers did not significantly affect total energy and fuel consumption, but significantly increased electricity consumption by 6.53%. Meanwhile, a 1% increase in circular workers significantly increased total energy consumption by 9.4% and electricity consumption by 5.53%, and reduced fuel consumption by 3.65%. The increase in commuter and circular workers in several regions has increased the transportation sector, such as KRL. This is one of the reasons why electricity has increased. In fact, circular workers have a significant impact on fuel consumption because based on a BPS survey, the closer the distance from the residence to the workplace will encourage workers to choose private transportation over public transportation. In addition, commuter and circular workers will consume more electricity at work than at home, resulting in an increase in electricity consumption in the province where they work. This is further exacerbated by circular workers who rent a second residence and create additional energy consumption in the household sector. Not only from the energy side, worker mobility also has a negative impact on workers' stress levels and work-life balance (Hämäläinen & Böckerman, 2002; Ezzedeen & Zikic, 2017; Lyons & Chatterjee, 2008; Markey et al., 2015; Walsh, 2012). However, it cannot be denied that this phenomenon can have a positive impact on the individual, household and regional economy (Högberg et al., 2007; Sandow, 2011; Sandow & Westin, 2010; Storey, 2010). One way to advance the economy through worker mobility is by reducing costs generated from the energy and social sectors.

5. Conclusion

The study used inferential analysis focuses more on the relationship between urban sprawl and demand for transportation or the relationship between transportation and energy consumption. The result shows cost reduction from the energy sector can be in the form of strengthening the odd-even policy with additional policies, such as implementing parking rates by maximizing workers' WTP; prohibiting parking in crowded areas and increasing public transportation in the area; and transitioning transportation from using fuel to using electricity. Although both produce energy, the emissions produced by electricity are smaller than fuel. Instead, the government needs to pay attention to electricity consumption in the workplace sector by providing a policy of limiting the use of energy consumption limits in the office or workplace sector. However, there are also limitations in this study. The research object in the form of provinces only consists of 33 provinces, without including North Kalimantan which has been ratified as the 34th province in Law No. 20 of 2012 on October 25, 2012. In addition, due to limited data available, the aspect of COVID19 which greatly affects worker mobility is not considered. The study also could not capture the effect of commuter and circular workers from different provinces on fuel consumption because both commuter and circular workers have the opportunity to refuel in their home province, and did not take into account circular and commuter workers who leave the province.

With the increase in commuter and circular workers, electricity and fuel have increased. If the demand for energy continues to increase, an energy crisis and greenhouse gas emissions could occur in Indonesia. This will increase the cost of commuter and circular workers. The way to minimize the resulting costs is to control the negative impacts through policies, one of which is through transportation and electricity policies in the workplace or office sector. One policy that can be implemented is to set parking rates that have been adjusted to the willingness to pay (WTP) of workers to pay for parking. It would be better if the parking fee was slightly above the worker's WTP, so that workers would think twice about using private vehicles. Another policy that can be implemented is a ban on parking in crowded areas and increasing public transportation in the area. If the workplace parking lot cannot accommodate all workers' cars and there is a parking ban around the area, workers will reconsider their decision to bring private vehicles and prefer to use public transportation.

Furthermore, the government can start encouraging people to transition to using electric transportation. According to the President Director of PT PLN, 1 liter of fuel produces 2.4 kilograms of CO2e. Meanwhile, if transportation switches to electric energy, 1 liter of fuel is equivalent to 1.2 kWh of electricity which only produces 1.02 kg CO2e emissions. However, electric energy can still produce emissions. Because the energy transition in the transportation sector is a good thing, the

government can prevent emissions through policies in other sectors, such as the use of electric energy in offices or workplaces, such as implementing energy limits used by considering the area of the building, the number of workers, and the type of work.

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References

Abozeid, A. S. M., & AboElatta, T. A. (2021). Polycentric vs monocentric urban structure contribution to national development. *Journal of Engineering and Applied Sciences*, *68*(11). doi: 10.1186/s44147-021-00011-1

Ali, M. (2021). Urbanisation and energy consumption in Sub-Saharan Africa. *The Electricity Journal*, *34*(10). doi: 10.1016/j.tej.2021.107045

Badan Pusat Statistik. (2020). *Hasil Survei Angkatan Kerja Nasional 2020 Analisis Mobilitas Tenaga Kerja Analisis Mobilitas Tenaga Kerja*.

Baltagi, B. H. (2005). *Econometric analysis of panel data* (3rd ed.). John Wiley & Sons, Ltd.

Cartone, A., Díaz-Dapena, A., Langarita, R., & Rubiera-Morollón, F. (2021). Where the city lights shine? Measuring the effect of sprawl on electricity consumption in Spain. *Land Use Policy*, *105*. doi: 10.1016/j.landusepol.2021.105425

Cass, N., & Faulconbridge, J. (2016). Commuting practices: New insights into modal shift from theories of social practice. *Transport Policy*, *45*, 1–14. doi: 10.1016/j.tranpol.2015.08.002

Chatterjee, K., Chng, S., Clark, B., Davis, A., De Vos, J., Ettema, D., Handy, S., Martin, A., & Reardon, L. (2020). Commuting and wellbeing: a critical overview of the literature with implications for policy and future research. *Transport Review*, *40*(1), 5–34. doi: 10.1080/01441647.2019.1649317

Chetty, R., Hendren, N., Kline, P., & Saez, E. (2014). Where is the land of opportunity? The geography of intergenerational mobility in the United States. *Quarterly Journal of Economics*, *129*(4), 1553–1623. doi: 10.1093/qje/qju022

Crow, D., & Millot, A. (2020). *Calculating the energy saved if home working becomes the norm, globally*. Energy Post.

Ezzedeen, S. R., & Zikic, J. (2017). Finding balance amid boundarylessness: An interpretive study of entrepreneurial work–life balance and boundary management. *Journal of Family Issues*, *38*(11), 1546–1576. doi: 10.1177/0192513X15600731

Hämäläinen, K., & Böckerman, P. (2002). *Regional labour market dynamics, housing and migration*

(No. 198; VATT Discussion Papers).

Hayat, N. Z., Kurniawan, M. L. A., & Wong, W.-K. (2023). The role of inequality in Indonesia: Does fiscal decentralization matter? *Jurnal Ekonomi Dan Studi Pembangunan*, *15*(2), 111–120. doi: 10.17977/um002v15i22023p111

Högberg, G., Pagani, M., Sundin, Ö., Soares, J., Åberg-Wistedt, A., Tärnell, B., & Hällström, T. (2007). On treatment with eye movement desensitization and reprocessing of chronic post-traumatic stress disorder in public transportation workers – A randomized controlled trial. *Nordic Journal of Psychiatry*, *61*(1). doi: 10.1080/08039480601129408

IEA. (2022). *Global Energy Crisis*.

Jafari, Y., Othman, J., & Nor, A. H. S. M. (2012). Energy consumption, economic growth and environmental pollutants in Indonesia. *Journal of Policy Modelling*, *34*(6), 879–889. doi: 10.1016/j.jpolmod.2012.05.020

Khasanah, D. U., & Kurniawan, M. L. A. (2024). Panel seemingly unrelated regression on employment in tourism sector: Evidence in Central Java province. *Eko-Regional: Jurnal Pembangunan Ekonomi Wilayah*, *19*(1), 11–19. doi: 10.32424/er.v19i1.16851

Li, K., & Lin, B. (2015). Impacts of urbanization and industrialization on energy consumption/CO2 emissions: Does the level of development matter? *Renewable and Sustainable Energy Reviews*, *52*, 1107–1122. doi: 10.1016/j.rser.2015.07.185

Lyons, G., & Chatterjee, K. (2008). A human perspective on the daily commute: Costs, benefits and trade-offs. *Transport Reviews*, *28*(2). doi: 10.1080/01441640701559484

Markey, S., Ryser, L., & Halseth, G. (2015). "We're in this all together": Community impacts of long-distance labour commuting. *Rural Society*, *24*(2), 131–153. doi: 10.1080/10371656.2015.1060717

Ministry of Energy and Mineral Resources. (2024). *Handbook of Energy & Economic Statistics of Indonesia (HEESI)*.

Muzayanah, I. F. U., Lean, H. H., Hartono, D., Indraswari, K. D., & Partama, R. (2022). Population density and energy consumption: A study in Indonesian provinces. *Heliyon*, *8*(9). doi: 10.1016/j.heliyon.2022.e10634

Navamuel, E. L., Rubiera Morollón, F., & Moreno Cuartas, B. (2018). Energy consumption and urban sprawl: Evidence for the Spanish case. *Journal of Cleaner Production*, *172*, 3479–3486. doi: 10.1016/j.jclepro.2017.08.110

Nayan, S., Kadir, N., Ahmad, M., & Abdullah, M. S. (2013). Revisiting energy consumption and GDP: Evidence from dynamic panel data analysis. *Procedia Economics and Finance*, *7*, 42–47. doi: 10.1016/S2212-5671(13)00216-5

Noussan, M., & Jarre, M. (2021). Assessing commuting energy and emissions savings through remote working and carpooling: Lessons from an italian region. *Energies*, *14*(21). doi: 10.3390/en14217177

Sadorsky, P. (2014). The effect of urbanization and industrialization on energy use in emerging economies: Implications for sustainable development. *The American Journal of Economics and Sociology*, *73*(2). doi: 10.1111/ajes.12072

Sandow, E. (2011). *On the road: Social aspects of commuting long distances to work*. Department of Social and Economic Geography, Umeå University, Sweden.

Sandow, E., & Westin, K. (2010). The persevering commuter - Duration of long-distance commuting. *Transportation Research Part A: Policy and Practice*, *44*(6), 433–445. doi: 10.1016/j.tra.2010.03.017

Sarkodie, S. A., & Adom, P. K. (2018). Determinants of energy consumption in Kenya: A NIPALS approach. *Energy*, *159*, 696–705. doi: 10.1016/j.energy.2018.06.195

Schettkat, R. (1997). Employment Protection and Labour Mobility in Europe: an empirical analysis using the EU's labour force survey. *International Review of Applied Economics*, *11*(1). doi: 10.1080/02692179700000006

Shahbaz, M., Hye, Q. M. A., Tiwari, A. K., & Leitão, N. C. (2013). Economic growth, energy consumption, financial development, international trade and CO2 emissions in Indonesia. *Renewable and Sustainable Energy Reviews*, *25*, 109–121. doi: 10.1016/j.rser.2013.04.009

Storey, K. (2010). Fly-in/Fly-out: Implications for community sustainability. *Sustainability*, *2*(5), 1161–1181. doi: 10.3390/su2051161

Subanti, S., Hakim, A. R., Pratiwi, H., Lestari, E. P., & Hakim, I. M. (2021). The factors influencing labor supply (the case for worker with non-permanent mobility in Central Java Province, Indonesia). *In Journal of Physics: Conference Series (Vol. 1918, No. 4, p. 042022)*. doi: 10.1088/1742-6596/1918/4/042022

Sulistiyaningsih, N. A., Arisetyawan, K., & Afifah, U. N. (2025). Factors affecting labor mobility Indonesia in 2022. *East Asian Journal of Multidisciplinary Research*, *4*(6), 2929–2946. doi: 10.55927/eajmr.v4i6.216

Walsh, D. (2012). Using mobility to gain stability: Rural household strategies and outcomes in long-distance labour mobility. *Journal of Rural and Community Development*, *7*(3), 123–143.

Wang, Y., Hou, L., Cai, W., Zhou, Z., & Bian, J. (2023). Exploring the drivers and influencing mechanisms of urban household electricity consumption in China - Based on longitudinal data at the provincial level. *Energy*, *273*. doi: 10.1016/j.energy.2023.127191