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The effect of urbanization on road energy consumption and CO_2 emissions in emerging megacity of Jakarta, Indonesia

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Abstract

Few studies have been made to explore quantitatively and systematically the impact of urbanization on transport energy use for cities in emerging countries. This paper tries to examine the relationship between urbanization and transport sector energy use in megacity Jakarta. Data from Jakarta Statistical Bureau for the megacity Jakarta and the period 2001-2014 are used and analyzed. Applying both the carbon-emissions-coefficient and the transport-energy-consumption method, we predicted the carbon emissions based on energy consumption, explored the characteristics of energy consumption and carbon emissions in different urbanization stages. Our results show the existence of co-integration and validated that urbanization is a major contributor in transport energy consumption. Income raises vehicle ownership and travel demand. The causality analysis finds that urbanization Granger causes transport energy consumption.

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Keywords: Urbanization; Transport Energy Use; CO_2 emissions; VECM; Granger Causality

1. Introduction

Urbanization in developing countries is known to be one of the most significant demographic changes in this century. This is due to the national economic restructuring and reshaping the lives of billions people. An analysis of the world urbanization trends released by the United Nations, in 2008, for the first time in history, 50% of population

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lived in urban areas and this number will increase to 60% by 2025 (UNDESA, 2008, 2012). The entire urban areas built in the developing countries will triple from 200,000 km^2 to 600,000 km^2 (between 2000 and 2030) (Angel, Sheppard, & Civco, 2005). In 2025, 60% of Indonesia's population will live in urban area (i.e., more than 160 million people). Jakarta population alone will rise about 30% to nearly 13 million people in 2030 (MGI, 2012). Although Jakarta metropolitan area and other urban areas in Java will continue to host the largest urbanizations, medium cities across the country will also grow at a steady pace (OECD, 2014; UNDESA, 2012).

Urbanization has enabled economic growth and innovation across the world. Urbanization contributes to three-quarters of global economic output and is often seen as an important aspect in the assessment of nations' development level (L. Li et al., 2010; MGI, 2011). However, urbanization has also contributed to the socio-economic and environmental challenges including climate change, pollution, congestion, and rapid growth of slums (Al-mulali, Binti Che Sab, & Fereidouni, 2012; Suzuki, Dastur, Moffatt, Yabuki, & Maruyama, 2010). More than half of the world's population now live in urban areas and are blamed for producing as much as 80% of greenhouse gas emissions (GHG) (Feng, Chen, & Zhang, 2013; IEA, 2012; UNDESA, 2008). Whilst urbanization leads to economic growth and living standard improvement, it also increases energy consumption and causes environment pollution (Al-mulali et al., 2012).

Urbanization is defined as a process of regrouping large permanent residents in moderately small areas and as a result forming crowded metropolises (Shahbaz, Loganathan, Sbia, & Afza, 2015). Further, urbanization is immigration from the agricultural area of non-agricultural area. The relationship between urbanization and energy use has been highly studied within energy economics field primarily by multinational empirical research. Results are, however, inconsistent. On the one hand, studies undertaken by H. Li, Mu, Zhang, & Li (2011), O'Neill, Ren, Jiang, & Dalton (2012), and Parshall et al. (2010) nominated urbanization as one of the most important factors affecting energy consumption in China, India, and the United States. These results were supported by studies undertaken in relation to developing countries by Jones (1991) and Parikh & Shukla (1995) and Poumanyvong & Kaneko (2010); in Japan by Sharif Hossain (2011) ; in Tunisia by (Shahbaz et al., 2015); in Canada by Lantz & Feng (2006); in regional China by Zhang & Lin (2012) and in ASEAN countries by Y. Wang, Chen, & Kubota (2015). On the other hand, Larivière & Lafrance (1999) and Ewing (2010) found a negative relationship between urbanization and energy consumption. Similarly, Liddle (2004) argues that urbanization in developed countries is associated with less transport energy use. In line with this argument, Liddle & Lung (2010) report that urban households in the US drive less than their rural counterparts. IEA (2008) also reports that each urban dweller consumes 11% less transport energy than the average US resident. Donglan, Dequn, & Peng (2010) found that residential CO_2 emissions decline in response to energy intensity and increases in response to income effects, in both urban and rural China. In addition, while Cole & Neumayer (2004), and (Liddle & Lung, 2010) found a positive relationship between urbanization and CO_2 emissions, Fan, Liu, Wu, & Wei (2006) located a negative relationship between the two variables in developing countries. Similarly, whilst Martinez-Zarzoso & Maruotti (2011) demonstrated an inverted U-shaped relationship between urbanization and CO_2 emissions, Zhu, You, & Zeng (2012) found little evidence to support that relation. Moreover, the impact of urbanization on urban transportation energy consumption is rarely discussed (Poumanyvong, Kaneko, & Dhakal, 2012; Ren, Wang, Wang, & Liu, 2014; Yuan, Ren, & Chen, 2015). Our article contributes to this debate by examining road energy consumption in a case study of megacity Jakarta.

Whilst previous studies focused largely on regional or national level of analysis our research aimed to estimate the elastic coefficients in the provincial "urban" level. On a regional level analysis, for instance, Liang & Yuchen (2012) conducted panel estimation for urbanization, energy consumption and CO_2 emissions using the IPAT model. Similarly, Feng et al. (2013) focused on a regional comparative analysis of CO_2 emissions using IPAT model. H. Li, Mu, Zhang, & Li (2011) analyzed the regional differences on impact factors of China's energy-related CO_2 emissions using STIRPAT model. Drawing on these previous studies, firstly we calculated the CO_2 emissions in Jakarta province over the period of 2001 to 2014. This is followed by an investigation of the relationship between urbanization, energy consumption, and CO_2 emissions using unit root tests, co-integration test, and Granger causality test. The research results indicate that understanding the relationship between these factors is key to guide the coordination and sustainable development of urbanization, energy consumption, and CO_2 emissions.

The rest of the paper is organized as follows. Section 2 covers general situation of case study area, estimation methods of CO_2 emissions and data issues. Section 3 reports and discusses the empirical results, and conclusions and policy implications are provided in Section 4.

2. Methods

2.1. General situation of the urbanization and energy transport use in Jakarta Province

Urbanization and energy consumption in Jakarta Province is high and has upwards trends (Fig.1). In 2001, the urban population was 7.42 million people and the total transport energy consumption was 3.41 million kL. From 2001 to 2014, the average annual transport energy consumption growth increased 16.61% while the urban population rose by 2.0% (BPS DKI Jakarta, 2002, 2015a, 2015b; ESDM, 2012b) .

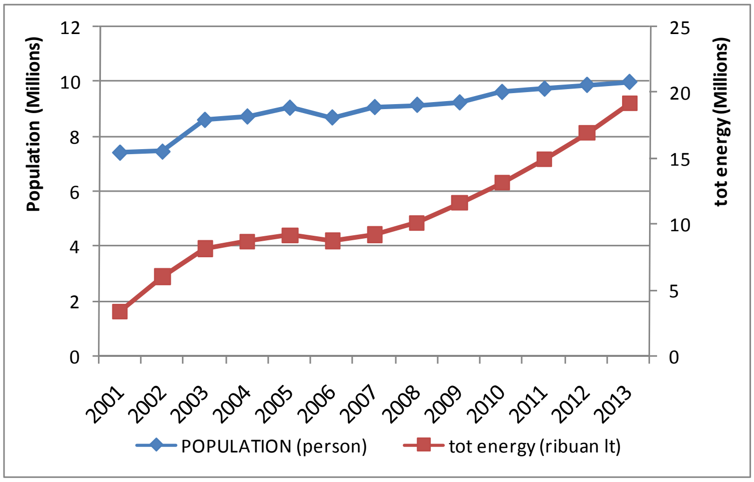

Fig. 1. Tendency of urbanization and transport energy use from 2001 to 2014.

2.2. Calculation method of carbon emissions

The carbon-emissions-coefficient method (CECM) was used to calculate carbon emissions. The CECM refers to the carbon emissions quantity per unit energy produced during consumption. According to the assumption of the International Panel on Climate Change (IPCC, 2007), using the CECM method, each energy source is standardized for calculation.

Carbon dioxide (CO_2) emissions can be divided into natural and artificial discharge. Artificial CO_2 emission is from human activities, mainly through fossil fuel and biomass combustion. The emission of CO_2 from fossil fuels accounts for more than 95% of artificial discharge (Zhao and Qin, 2007). The vast majority (94%) of the energy used in transport comes from fossil fuels, which is responsible for emissions of 6.9 Gt CO_2–eq carbon dioxide (CO_2) and other greenhouse gases (GHGs) whose increasing concentration in the atmosphere is the dominant factor in the warming of the climate (IPCC, 2014). Therefore, fossil fuel sources were used exclusively to calculate the carbon transport emissions in Jakarta Province. Because Indonesia has no direct carbon emissions test data, the majority of studies were based on estimates of energy consumption (ESDM, 2012b; Hasibuan, Soemardi, Koestoer, & Moersidik, 2014; Nur, Lestari, & Uttari, 2010). Following S. Wang, Fang, Guan, Pang, & Ma (2014), therefore, carbon emissions in Jakarta Province were calculated by using formula Eq. (1).

$$CE = \sum CEi = \sum \ PECi \times Fi \qquad (1)$$

where *CE* represents CO_2 emissions from fossil energy consumption; *i* denotes the different types of fossil fuel (including gasoline, kerosene, diesel, fuel oil, and natural gas); PECi represents the consumption of various fossil fuels *i*; and *Fi* is the CO_2 emissions coefficient of fossil fuels *i* (Table 1).

All the analyses in the paper are based on the available data from Jakarta Statistical Yearbook (BPS DKI Jakarta, 2002, 2006, 2015a, 2015b), Indonesia Energy Statistical Yearbook (ESDM, 2010, 2012a). In addition, according to the comprehensive report "Green House Gas Emissions of Transportation Sector" from the Energy Data Centre and Mineral Resources, Ministry of Energy and Mineral Resources, Indonesia and other relevant empirical data (ESDM, 2012b; IPCC, 2006a; Nur et al., 2010), the coefficients of carbon emissions for gasoline, diesel, and natural gas were 0,069 t GJ^{-1}, 0,062 t GJ^{-1}, and 0,056 t GJ^{-1}, respectively.

Table 1. CO_2 emissions coefficients. Source: IPCC (2006) and the National Data Centre on Energy and Resources of the Ministry of Energy and Mineral Resources

Sources	Gasoline	Diesel	Natural Gas
CO_2 emissions coefficients (ton/GJ)	0,069	0,062	0,056

2.3. Econometric Analysis Methods

Imai (1997) has used the equation E=P*e* to analyze relation between population and environmental issues. In the equation E denotes total energy consumption, P denotes total population and e denotes per capita energy consumption. The author has linked urbanization and per capita consumption by the equation:

$$Lne = aU + b \quad (2)$$

where U denotes proportion of urban population and *a* and *b* are co-efficient.

Similarly, (Poumanyvong et al., 2012) in the study of impact of urbanization in the national transport energy, used the model incorporating share of services in the GDP along with population, GDP per capita and urbanization. Mathematically, the model was represented as

$$lnEnergy_{it} = \propto_1 + \beta_1 ln(P_{it}) + \beta_2 ln(A_{it}) + \beta_3 ln(URB_{it}) + \beta_4 ln(SV_{it}) + u_{it} \quad (3)$$

We follow the model developed by Imai (1997), Acharya, Ale, & Shakya (2014) and (Azlina, Law, & Nik Mustapha, 2014). On the basis of modern econometrics techniques, the dynamic causal relationship between urbanizations and transportation energy consumption has been examined in this paper. The testing procedure involves the following three steps (Ghosh & Kanjilal, 2014; Hossain, 2012; Rezitis & Ahammad, 2015; Shahbaz et al., 2015). The first step whether each variable contains a unit root has been examined (to test the stationary of the series). Search for co-integration among the time series must be preceded by testing the stationary properties of each of the variables. Of the most commonly used tests are the ADF (Dickey & Fuller, 1981), PP (Phillips & Perron, 1988), DF-GLS (Elliott, Rothenberg, & Stock, 1996) and Ng–Perron (Ng & Perron, 2001). In this study, Augmented Dickey Fuller (ADF) test and Phillips-Perron (PP) test will be utilized. If the variables contain a unit root, the second step is to test whether there is a long run co-integration relationship between the variables. The long-run and short-run elasticities of carbon emissions with respect to urban transport energy use and urbanization have been calculated using the econometric statistical method. If a long-run relationship between the variables is found, the final step is estimate the vector error correction model (VECM) in order to infer the Granger causal relationship between the variables. The application of VECM is to investigate the causal relationship between the variables once co-integration relationship exists between the series. It is argued by (Granger, 1969) that the VECM is an appropriate approach to examine causality between the variables when series are integrated at I(1).

3. Result and Discussions

The urban population rate from 2001 to 2014 which was obtained from Jakarta Statistical Yearbook shows a trend toward fast growth in the beginning stages of urbanization, which slows as urbanization matures. Energy consumption and carbon emissions are tendency of positively correlated with this trend as shown in Fig.2.

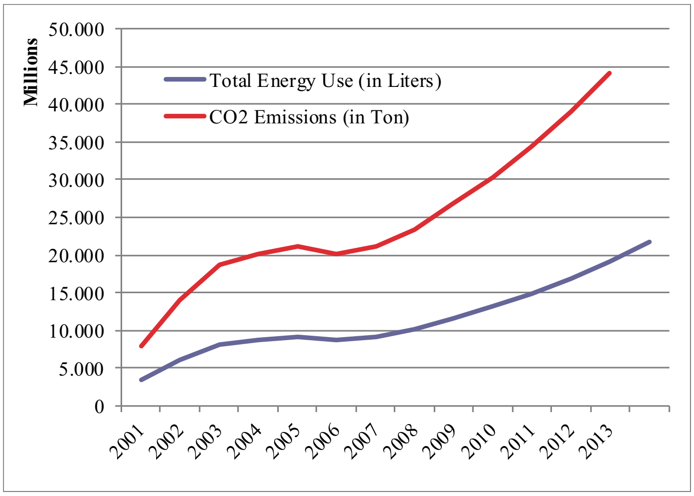

Fig. 2. Tendency of positive correlation between road energy consumption and CO_2 emissions in Jakarta Province from 2001-2014

The co-integration test requires the data to be stationary. Therefore, to address this issue, we have applied traditional unit root tests such as ADF test by Dickey & Fuller (1981); PP test by Phillips & Perron (1988). The unit root test for the level of data shows both the total energy and the population is not stationary at level. Therefore, we tested further for the lag 1 (I(1)), the result of this test shows both the total energy and the population has been stationary (Table 2). This supports us for further analysis.

Table 2. Results of Unit Root Tests

Method	Statistic	Prob.**	Cross-sections	Obs
Null: Unit root (assumes common unit root process)				
Levin, Lin & Chu t*	-1.42790	0.0767	2	23
Null: Unit root (assumes individual unit root process)				
Im, Pesaran and Shin W-stat	-3.07906	0.0010	2	23
ADF - Fisher Chi-square	16.1062	0.0029	2	23
PP - Fisher Chi-square	21.0998	0.0003	2	24

** Probabilities for Fisher tests are computed using an asymptotic Chi -square distribution. All other tests assume asymptotic normality.

Because stationary at the same lag, then we apply the co-integration test between the variables to determine whether to use VECM or a VAR as the next step. The co-integration means that there are long-run equilibrium relationship between two or more variables. The long-run equilibrium relationship could be identified by the absence of another error influence the dependent variable in the equation (the influence of error means the imbalance between the variables studied because there are other variables that affect the dependent variable through the variable error). So that their co-integration can be seen when the error of the long-run equation has no unit root at the level (stationary on the level).

Table 3 shows the results of long-run analysis. The value of statistics probability F which is smaller than alpha 5%, indicating that the simultaneous equation long term *LNTOT* = -49 097 + 4,505 *LNPOP* has already significant. Then the statistical probability value t which is also smaller than alpha 5% showed that in partial *LNPOP* indeed significantly affect *LNTOT* variables. This means that long-term balance between total energy use and population can be written by an equation:

$$LNTOT = -49\ 097 + 4{,}505\ LNPOP \quad (4)$$

where *LNTOT* represents total transport energy use and *LNPOP* represents total urban population (as a proxy of urbanization). This equation means *LNPOP* affects *LNTOT* in the long run elasticity of 4.5%. It shows in the long term, any increase in population by 1%, it will be followed by an increase in total energy use of transport by 4.5% by keeping other things constant.

Table 3. The result of long-run analysis

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-49.09723	6.068779	-8.090133	0.0000
LNPOP	4.505050	0.378859	11.89109	0.0000

R-squared	0.921772	Mean dependent var	23.06577
Adjusted R-squared	0.915253	S.D. dependent var	0.483077
S.E. of regression	0.140630	Akaike info criterion	-0.953806
Sum squared resid	0.237321	Schwarz criterion	-0.862512
Log likelihood	8.676639	Hannan-Quinn criter.	-0.962257
F-statistic	141.3979	Durbin-Watson stat	2.283465
Prob(F-statistic)	0.000000		

Having acquired of the long-run equation that is statistically significant, then the next step is to test stationarity of the residuals obtained from the long-run equation. In this test, the null hypothesis is that the residuals have a unit root (not stationary) at the level. Table 4 shows the results of test in which the statistical probability of ADF smaller than alpha 5%, which shows the rejection of Ho. It is means there is no unit root in the residual data of long-run equation (residual data has been stationary) at the level. Because the examination of unit root tests indicates that the long-run residual equation between *LNTOT* and *LNPOP* does not contain unit root (stationary) at the level, it can be concluded there is a long-run equilibrium between the two variables (co-integration).

Since the existence of long-run (co-integration) relationship between the variables such as urban transport energy consumption and population (as proxy of urbanization), lead us to apply the VECM Granger causality approach. The result of VECM Granger causality approach shows the causality between the variables both for long-and-short runs. The results of Granger causality test are summarized in Table 5. The feedback effect exists between urbanization and urban transport energy use. Urban transport energy consumption is Granger caused by urbanization. The appropriate information about the direction of causality between the variables provides an evidence for policymakers to formulate urban, energy, and economic policy to sustain long run economic growth.

Table 4. The result of residual test analysis

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.919178	0.0024
Test critical values:	1% level	-4.057910	
	5% level	-3.119910	
	10% level	-2.701103	

*MacKinnon (1996) one-sided p-values.
Warning: Probabilities and critical values calculated for 20 observations and may not be accurate for a sample size of 13

Augmented Dickey-Fuller Test Equation

Variable	Coefficient	Std. Error	t-Statistic	Prob.
RESID_ECM_1(-1)	-1.255212	0.255167	-4.919178	0.0005
C	0.017967	0.034345	0.523130	0.6113

R-squared	0.687485	Mean dependent var	0.013859
Adjusted R-squared	0.659075	S.D. dependent var	0.212018
S.E. of regression	0.123795	Akaike info criterion	-1.199747
Sum squared resid	0.168576	Schwarz criterion	-1.112831
Log likelihood	9.798353	Hannan-Quinn criter.	-1.217612
F-statistic	24.19831	Durbin-Watson stat	0.893480
Prob(F-statistic)	0.000457		

Table 5. Granger causality test, LNPOP (Total population) to LNTOT (Total transport energy use)

Null Hypothesis:	Obs	F-Statistic	Prob.
LNPOP does not Granger Cause LNTOT	12	3.50158	0.0883
LNTOT does not Granger Cause LNPOP		12.7522	0.0046

Our results support earlier findings that urbanization is an increasingly important determinant of GHG emissions in the developed and developing world (Cole & Neumayer, 2004; Dietz & Rosa, 1997; Poumanyvong et al., 2012; Shahbaz et al., 2015; Shi, 2003; York, Rosa, & Dietz, 2003). We bridge a gap in the literature by considering the urbanization−emissions relationship by case study of megacity in developing region and strength of environmental policy. Previous studies by STIRPAT (stochastic environmental impacts by regression on population, affluence, and technology)- based approaches have reported that urbanization's impact on CO_2 emissions is smaller in higher-income countries than in other countries but with a positive elasticity for all income levels (Martinez-Zarzoso & Maruotti, 2011; Poumanyvong et al., 2012). Our findings indicate that the relationship between urbanization with transport energy use and carbon emissions; shows the strong environmental policy and its implementation are essential to reduce the environmental footprint of urbanization. That finding, highlighting the importance of environmental policy in urban scale, is a contribution of this article to the literature.

A novel approach of our analyses in this paper is that we employ a time series data in the provincial level rather than national level, thereby allowing us to explore changes over time in specific locations. A limitation of our analyses is that we are unable to identify specific policies that might impact the elasticity in different levels of urbanization and development in Jakarta megacity. That issue is an important for the next step. Variables not explicitly examined here include urban density, the proportion of specific urban road energy end points (e.g., gasoline, diesel, LPG, electricity) met using non-fossil sources, and weather. We plan that evaluations for our future research. Our data rely on the published data by self-reported values from provincial and national authorities (e.g. BPS, BPLHD, DISHUB, and ESDM); we were unable to verify raw-data estimates. In addition, our data cover direct emissions only, not life cycle emissions; others have found that life cycle approaches shed important and useful light on understanding the environmental impacts of urbanization (Heinonen & Junnila, 2011; Kennedy et al., 2009; Ramaswami, Hillman, Janson, Reiner, & Thomas, 2008).

Finally, the results show that emission in the Jakarta megacity is expected to increase at high rate if there is lack of policy intervention in the future. The high emission of CO_2 is due to rapid increase in the number of motorcycles and private vehicle and poor service of public transportation. The positive and statistically significant relationship is found between income per capita and vehicle ownership. As shown on Table 6, GDPKT (income per capita) Granger Cause to VHCKPT (vehicles per capita).

Table 6. Granger causality test for GDPKT (Income per capita) to VHCPKT (Vehicles per capita)

Null Hypothesis:	Obs	F-Statistic	Prob.
VHCKPT does not Granger Cause GDPKPT	12	7.07921	0.0260
GDPKPT does not Granger Cause VHCKPT		0.68170	0.4303

4. Conclusions

This paper explores systematically the influence of urbanization on urban transport and road energy use in the Jakarta megacity during 2001–2014. The main findings of this study is that urbanization has a positive influence on urban transport and road energy use in the Jakarta megacity. The elasticity of urbanization is estimated as 0.45 in this study. For instance, a 1% increase in urbanization raises urban transport energy use in Jakarta by 4.5%. It shows that urban transport energy consumption in Jakarta is greatly affected by the number of people living in urban areas. The city needs to use land available in a centralized way to reduce private transport use. Reducing work places in a designated part of the city will reduce the energy use by encouraging walking or use of public transport. Similarly, regulatory policies like fuel economy and emission standard for vehicles, auto age restriction, awareness campaigns could be some other measures to control emission and energy consumption by transportation in the Jakarta megacity.

The research has some limitations. First, although it focuses on urban road transport, electric and LPG vehicles are not considered in the study because they have a small contribution to urban energy consumption. Second, the number of vehicles that is considered in this study is only the total registered vehicles in Jakarta megacity only, without considering commuter vehicles from surrounding areas that travel through Jakarta during the working and weekend day.

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