International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(2), 669-675.

Interconnected Forces: Analyzing Urbanization, Economic Growth, Energy Consumption, and Forest Area in the Top 10 Populous Nations' CO_2 Emissions

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Received: 25 October 2023 **Accepted:** 27 February 2024 **DOI:** https://doi.org/10.32479/ijeep.15545

ABSTRACT

Economic progress is often seen as a means to enhance living standards, yet it often comes with an unintended consequence: a decline in environmental well-being. This research seeks to validate the Environmental Kuznets Curve (EKC) theory within the top 10 most populous nations and scrutinize the impact of urbanization, economic advancement, energy usage, and forest coverage on CO_2 emissions. Utilizing data sourced from the World Development Indicator spanning from 2000 to 2019, this study employed a robust analytical approach known as the generalized method of moments (GMM) dynamic panel data, validated through Sargan and Arellano-Bond tests. The findings affirmed that economic growth, energy consumption, and forest area exerted significant influence on carbon dioxide emissions, aligning with the EKC hypothesis. However, contrary to expectation, urbanization didn't display a discernible impact on emissions, likely due to well-integrated transportation systems and higher educational standards prevalent in urban settings. This underscores the necessity for a sustainable economic growth strategy, advocating for industries with minimal pollution and eco-friendly products conducive to easy recycling. Furthermore, initiatives aimed at expanding forested areas should consider innovative techniques like vertical garden-based reforestation.

Keywords: CO_2 Emissions, Urbanization, Environmental Kuznets Curve, Energy Consumption, Generalized Method of Moments
JEL Classifications: O18, P18, P25, R11

1. INTRODUCTION

Climate change and global warming are two issues often discussed in the literature (Rosita et al., 2021). According to the evidence provided by the Intergovernmental Panel on Climate Change (IPCC), global warming is currently a major challenge. The main cause of this issue is the emission of greenhouse gases (GHG) such as CO_2 (Wang and Su, 2019). Throughout the 20th century, increases in economic growth were driven by fossil energy processes that produce high carbon dioxide. Due to the importance of fossil fuels, it seems logical for policymakers to consider that any reduction in CO_2 release will hinder economic growth and could trigger a downturn (Shahbaz et al., 2017). The increase in global warming and climatic change shows that the economic development being carried out pays less attention to environmental factors, therefore the quality is decreasing. To overcome this challenge, the green economy concept emerged, which aims to achieve growth and development without causing a negative impact on the environment (Demissew Beyene and Kotosz, 2020). Global warming is triggered by an increase in world economic activity, international trade, and energy use (Liu, 2021). There is a concern that environmental pollution poses serious threats to natural resources and health. Hence policymakers focus on sustainable development (Al-Rdaydeh et al., 2021).

The Intergovernmental Panel on Climate Change (IPCC) stated that there had been an increase in global warming since 1995 due to human activities and energy use that produce greenhouse gas (GHG) concentrations. This statement is reinforced by the

World Bank (2010) that carbon dioxide emissions cause 58.8% of global warming and climate change. Economic development is expected to improve the quality of life of the community. However, the developmental process has side effects or negative externalities, such as declining environmental quality. According to the United Nations Framework Convention on Climate Change (UNFCC), human activities directly or indirectly cause environmental changes. Several studies discuss the factors that affect CO_2 emissions. An increase in economic activity is closely related to environmental degradation, such as a large increase in greenhouse gas (GHG), especially CO_2 (Zhang et al., 2019). Also, the relationship between economic growth and a decrease in environmental quality is explained by The Environmental Kuznets Curve Hypothesis (EKC) with an inverted U-shape (Demissew Beyene and Kotosz, 2020). The hypothesis explains that in the early stages of economic growth, there is a positive relationship between growth and environmental degradation, and then pollution levels decrease as the industry adopts cleaner technologies (Kanjilal and Ghosh, 2013). Therefore, all countries are responsible for resolving the contradiction between economic growth and CO_2 emissions (Xie et al., 2019; Yanto et al., 2024).

Studies related to the factors that affect emissions have been carried out. However, they were only conducted within the scope of the country and regions with the same economic, social, and cultural characteristics. No literature focuses on demographics, especially those that discuss the relationship between population and increased emissions. This paper focuses on CO_2 emissions in the ten most populous countries in the world. A high population density increases energy demand as well as vulnerability. Therefore, this study examines the factors influencing CO_2 emission levels from 2000 to 2019. The independent variables were Gross Domestic Product (GDP), urbanization, use of electrical energy, and forest area. The structure of this paper consists of the following: Section 1 explains the background, while 2 discusses the relevant theory and previous research. Section 3 describes the methodology, and 4 presents the results and discussion. Finally, section 5 discusses the conclusions.

2. LITERATURE REVIEW

2.1. Effect of Urbanization on CO_2 Emissions

The development of urban areas with all their attractiveness leads many more people to be interested in moving to the cities or urbanization (Pujiati et al., 2019). Urbanization has three effects on global CO_2 emission (Pujiati, Nihayah, et al., 2023; Voumik et al., 2023; Zhu and Peng, 2012); Firstly, it increases household energy consumption, whereas urban areas use more energy than rural, hence CO_2 emission is increased. Secondly, urbanization escalates the demand for housing and its materials, such as cement which is an important source of carbon dioxide. Thirdly, the increasing demand for housing requires cutting down trees and conserving grasslands, thereby reducing CO_2 absorption. An increase in urbanization and population significantly soars carbon dioxide release in the long and short term. Countries with large populations, such as Nigeria and Ethiopia, tend to have emissions that increase more rapidly following energy consumption (Poku, 2016). The rate of urbanization in developed countries continues to increase while developing nations are expected to experience the greatest increase, which has a negative impact on the natural environment (Khoshnevis-Yazdi and Shakouri, 2018; Pujiati, Yanto, et al., 2023).

Urbanization has a positive and significant effect on carbon dioxide emissions in APEC countries (Wang et al., 2020). A 1% increase in urbanization simultaneously raises emissions by 0.274%. Furthermore, urbanization improves the economy by agglomerating industries and economic activities that maximize people's resources and potential, but it increases CO_2 emission levels (Handayani et al., 2022; X. Liu et al., 2021; Prasetyo et al., 2022; Pujiati, Yanto, et al., 2023). As urbanization accelerates, the areas play a major role in energy usage, hence consumption and emissions are elevated in China (Zhang and Lin, 2012). In another study, there were higher levels in urban areas than in rural (Li et al., 2015; Pujiati, Murniawaty, et al., 2022a). On the other hand, urbanization significantly increases energy use intensity but does not significantly raise emission levels. This is due to the pattern of increasing technology adaptation that is environmentally friendly (Pujiati, Oktavilia, Fafurida, & Wahyuningrum, I.F. Damayanti, 2020; Shahbaz et al., 2017; Sundram et al., 2021).

2.2. Effect of GDP on CO_2 Emissions

The EKC hypothesis explains the improvements in environmental quality at higher per capita income levels caused by changes in output composition, the introduction of production technology, and demand for improvements, leading to more stringent regulations (Sunday, 2016). This hypothesis explains that environmental damage increases with economic activity, and income increases with better environmental quality (Pujiati, Nurbaeti, et al., 2023; Zilio and Recalde, 2011).

Empirical results showed there is a quadratic relationship between income growth and CO_2 emissions in China and Japan (Ouyang and Lin, 2017). There is a significant correlation between economic growth and carbon dioxide release which has the same trend in the 1991-2011 period except during the crisis (Park and Hong, 2013). Higher economic growth affects a cleaner and quality environment. Therefore, it is necessary to make policies that reduce emissions (Mirza and Kanwal, 2017). Every 1% increase in economic growth promotes CO_2 emissions by 0.66% between 1980 and 2013 in Kuwait (Salahuddin et al., 2018).

An increase in the investment value of GDP facilitates emissions, hence policymakers create rules to make technological investments more efficient and environmentally friendly (Loures and Ferreira, 2019). Previous studies showed a paradox: economic growth and energy consumption are significant sources of carbon emissions in developing countries but not in developed ones (Waheed et al., 2019). Economic growth drives an increase in CO_2 emissions. Therefore, initiating changes at a strategic level in terms of industrial structure and output optimization is important. This aims to reduce carbon dioxide release without affecting growth rates (Khoshnevis-Yazdi and Shakouri, 2018). In other cases, the GDP of the industrial sector and the manufacturing sector negatively affect the quality of the environment in Indonesia (Pujiati et al., 2020).

2.3. Effect of Electricity Consumption on CO_2 Emissions

The degradation of the environment can be caused by energy consumption (Oktavilia et al., 2019). The increasing use of electrical energy has an effect on the environment, such as depletion of resources, global warming, and carbon dioxide emissions. The fast and steady long-term economic growth in China since the reform and opening-up strategy has led to a large increase in the demand for various energy sources, including electricity (Kanjilal and Ghosh, 2013; Pujiati, Nihayah, et al., 2022). This electrical energy is generated from coal as the major material for steam power plants. Coal greatly contributes to direct CO_2 emissions, while electricity is the main source of indirect release. However, electrical energy is larger than coal, contributing 76.57% of carbon in 2017 in China (Hu et al., 2021; Oktavilia et al., 2022; Pujiati, Murniawaty, et al., 2022b). The rapid technological development such as big data and cloud computing is predicted to increase energy consumption from 3% in 2017 to 4.5% in 2025, promoting carbon emissions (Liu et al., 2020).

Electricity usage has a positive and significant effect on carbon emissions in China, the United States, India, Japan, and the United Kingdom, but it shows a negative relationship between consumption and carbon release in France (Rahman, 2020). Therefore, electrical energy needs to be used with a long-term investment strategy to increase its distribution efficiency. In the short and long term, electricity consumption positively and significantly influences CO_2 release in Kuwait. Every 1% increase in its usage leads to a rise in CO_2 emissions of 0.71% (Salahuddin et al., 2018). During the Covid-19 pandemic, an increase in energy consumption, especially electrical energy, raises CO_2 release (Iqbal et al., 2021).

2.4. Effect of Forest Area on CO_2 Emissions

The increase in greenhouse gases (GHG) in the atmosphere is partly due to the degradation of forest areas (Sannigrahi et al., 2020). Moreover, Shittu et al. (2018) found that deforestation had a positive and significant effect on increasing emission levels in Malaysia from 1981 to 2014 period. In the long term, forest area significantly negatively impacts CO_2 release (Waheed et al., 2019). An increase of about 6-17% is due to deforestation worldwide. In developed countries, there are climate change mitigation policies, namely Reducing Emissions from Deforestation and Degradation (REDD+), which aims to protect forests. REDD+ Norway – Guyana during the 2010-2015 period has reduced deforestation by 35% and avoided 12.8 million tonnes of CO_2 emissions (Roopsind et al., 2019).

3. RESEARCH DATA AND METHODS

3.1. Data Types and Sources

This study used panel and cross-sectional data, namely the ten most populous countries, including China, India, the US, Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, Russia, and Mexico, from 2000 to 2019. The data were sourced from the World Development Indicator database owned by the World Bank. Table 1 summarizes the sources and operational definitions of the variables.

3.2. Model Specifications and Data Analysis Techniques

To examine the effect of independent variables on CO_2 emission level, the theory and empirical findings were used to develop the following model:

$$CO_{2it} = \beta_0 + \beta_1 URBAN_{it} + \beta_2 GDP_{it} + \beta_3 ELECTRIC_{it} + \beta_4 FOREST_{it} + \varepsilon_{it} \quad (1)$$

The generalized method of moments (GMM) dynamic panel data was used. Sabir (2019) stated that GMM is the most suitable technique for obtaining unbiased estimators in endogeneity. In the GMM model, there is no prerequisite for the assumption of data normality.

4. RESULTS AND DISCUSSION

Figures 1 and 2 show that during the 2000-2019 period, an increase in GDP is followed by an elevation in CO_2 emissions in China, India, the United States, Indonesia, Brazil, Pakistan, Nigeria, Bangladesh, Russia, and Mexico. This upward trend is correlated with an increase in Gross Domestic Product (GDP) due to consumption, investment, and international trade transactions. In the early 2000s, the United States contributed the largest CO_2 release, but from 2006 to 2019, China became the largest emitter due to industrialization and trade policies to become the largest economy in the world.

Figure 3 shows there is an increase in the average urban population from 2000 to 2019. Residents move to urban areas to get a decent standard of living; hence they can improve their welfare. Additionally, electricity consumption increases with population growth, as indicated in Figure 4.

Figure 5 shows that the increase in population has caused forest areas to experience a significant decline from 2000 to 2019. Also, human needs for developing settlements and industrial estates have led to the conversion of agricultural land and forest areas. This decrease has a negative impact on environmental quality.

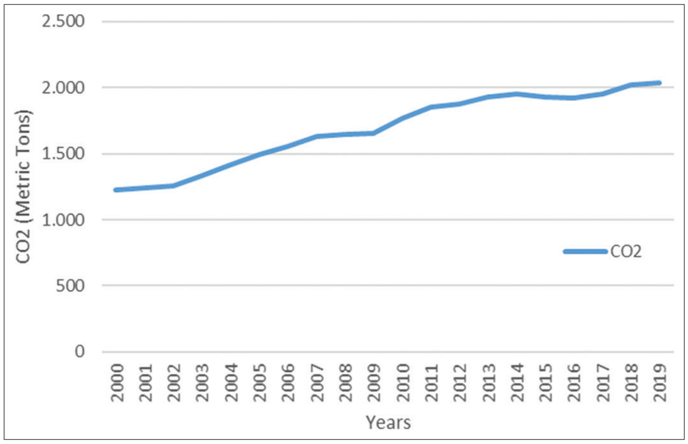
4.1. Descriptive Statistics of Variables

Table 2 presents the descriptive statistic results on each variable, which has an average value of observation (mean). Based on the observation in Table 2, the average value in each case has a value that is relatively lower than the standard deviation, and each variable shows a relatively normal distribution. This implies that each variable does not have a large deviation from the average value. The standard deviation provides a more comprehensive and accurate estimate of the spread. In the same way, the maximum and minimum values describe each variable in terms of the highest and lowest values as they appear in each series.

Table 1: Data information

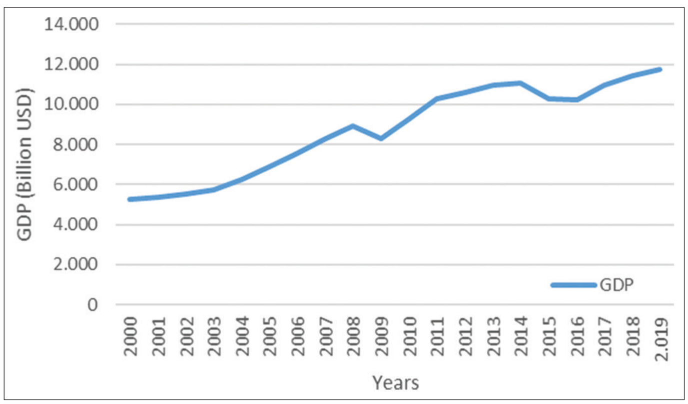
Variables	Acronym	Measure	Sources
CO_2 Emission	CO_2	Million-kilo ton	World Development Indicator
Urbanization	Urban	Number of urban population	World Development Indicator
Gross Domestic Product	GDP	Number of GDP	World Development Indicator
Electricity Consumption	Electric	kwh	World Development Indicator
Forest Area	Forest	Area (km^2)	World Development Indicator

Figure 1: Average CO_2 Emissions



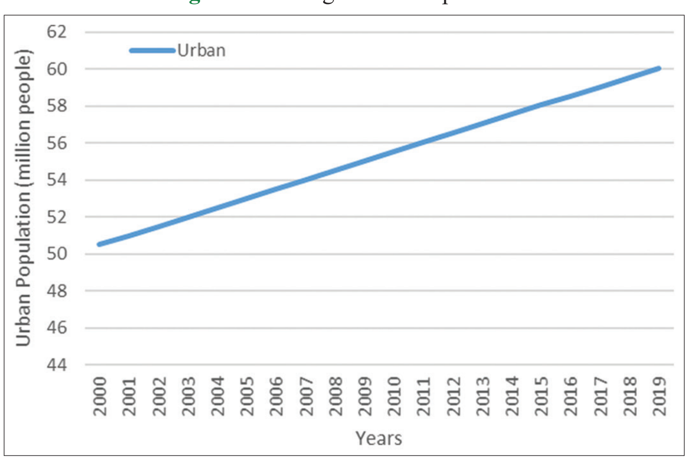
Source: World Development Indicator, World Bank

Figure 2: Average GDP



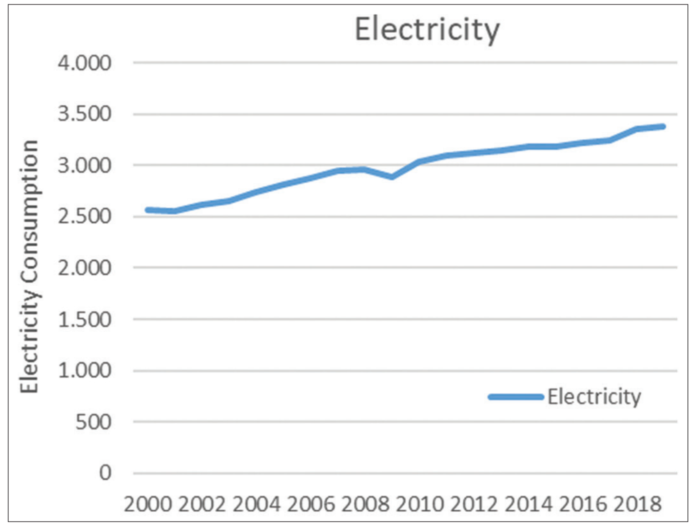
Source: World Development Indicator, World Bank

Figure 3: Average Urban Population



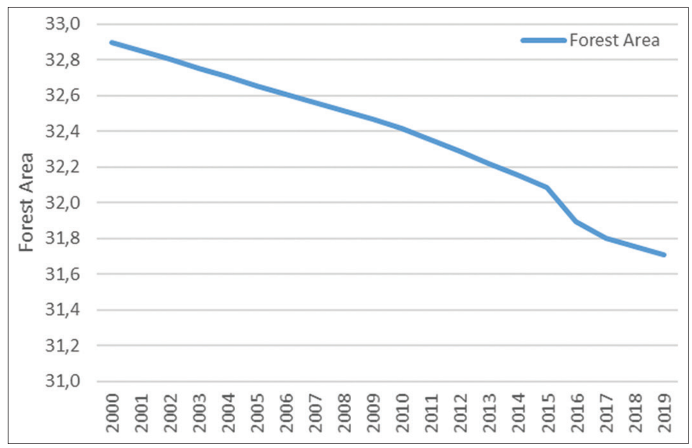
Source: World Development Indicator, World Bank

Figure 4: Average Consumption of Electrical Energy



Source: World Development Indicator, World Bank

Figure 5: Average Forest Area



Source: World Development Indicator, World Bank

Table 2: Variable descriptive statistics

Variable	Mean	Minimum	Maximum	Standard Deviation
CO	1684.379	20.95000	9876.500	2459.768
Urban	55.28555	23.59000	86.82000	20.84815
GDP	8745.435	413.0800	65297.52	14346.07
USE	2979.644	115.6700	13827.79	3907.392
FA	32.37480	4.890000	65.93000	17.25739

4.2. The Panel Data GMM Estimation Results

To determine the dynamic panel model of the best GMM (Generalized Method of Moments), three criteria were used, namely unbiased, validity, and consistency. A good GMM model is a valid, consistent, and unbiased model. The first test is an unbiased one which can be carried out by comparing the estimated coefficients from the OLS estimate and the fixed effect. The OLS (Ordinary Least Square) method causes the estimate to be biased upwards, while the fixed effects cause downward biased. The model is said to be unbiased when the estimated coefficient is below the OLS estimate and above the fixed effect. Based on Table 3, it can be seen that the GMM coefficient value is greater than the FEM and smaller than the Pooled value. The value of the GMM coefficient is between the FEM (Fixed Effect Model) and PLS (Partial Least Square) values, hence the model is declared to be unbiased.

The second is the validity test by comparing the J-statistic model value with an alpha of 5%. Based on the results, the value is 7.525019 which is greater than 5% alpha, hence the model is said to be valid.

The next stage is to test the model specifications. The estimation results of the best dynamic panel model can be seen from two criteria, namely, the instrument variables used are valid as seen from the Sargan Test and the estimates used are consistent as seen from the Arellano-Bond Test. The Sargan test for overidentifying restriction is used to determine whether there is a problem with the instrument's validity. The valid meaning of this discussion is that there is no correlation between the instrument and the error component. Also, the null hypothesis of the Sargan test states that the instrument has no problem with the validity of the valid instrument. The results showed that the pval value of the Sargan test is 0.7683, and the instrument used is valid.

Meanwhile, the Arellano-Bond test was conducted to test the consistency of the estimates obtained from the GMM process. The Arellano-Bond test results, namely the AR (2) probability value is 0.7209, which is greater than 5% alpha. It can be concluded that the model is consistent with the second-order first difference, and there is no autocorrelation between the residuals and the endogenous variables. Based on the Sargan and Arellano-Bond Test results, the robust model uses a dynamic panel model with the Arellano-Bond GMM method.

The panel data regression model estimation was used to determine the effect of urbanization, Gross Domestic Product (GDP), Electrical Energy Consumption, and Forest Area on carbon dioxide (CO_2). The emission model (CO) results completed the assumptions in the dynamic panel data regression using the Arellano-Bond GMM estimation. The results can be seen in Table 4.

Based on the results, the emission variable lag 1, GDP, and the use of electrical energy significantly affect CO_2 emissions at 5% alpha. This is seen from the probability value smaller than 5% alpha. Furthermore, the area of forest land significantly affects emissions at 10% alpha, as seen from the probability value of less than 10%. However, urbanization has no effect on emissions, where the probability value is greater than 5% and 10% alpha.

Based on the results, the urbanization variable is negative but does not significantly affect carbon dioxide. The regression coefficient of –20.08194 showed that every 1% increase in urbanization is followed by a decrease in carbon dioxide of 20.081 million kilotons on cateris paribus. This decrease is in accordance with Hu and Tang (2013), Azzam and Khan (2016), Azam and Khan (2016), Li et al., (2022). The existence of urbanization does not affect the emissions produced in urban areas because they tend to have an integrated system and the availability of public transportation. People in these areas switch from their private transportation and take advantage of this public means (Taki et al., 2017). According to Taki et al., urban spatial planning accommodates transportation modes that are easy and accessible to the people. One of these efforts is Transit-Oriented Development (TOD).

Table 3: Comparison of FEM, GMM, and PLS model coefficient values

Model	Coefficient	Std. Error	t-Statistic
FEM	0.850206	0.013687	62.11657
GMM	0.910507	0.032588	27.93977
PLS	1.045694	0.000971	1076.420

GMM: Generalized method of moments

Table 4: Estimated Model Emissions (CO) of GMM Arellano-Bond

Variable	Coefficient	t-statistic	Prob.
C0(-1)	0.910507	27.93977	0.0000
Urban	−20.08194	−1.198455	0.2324
GDP	0.004359	2.851590	0.0049
USE	0.304907	4.205358	0.0000
FA	−36.14575	−1.732787	0.0000
J-statistic	7.5250190.0849		
Prob. (J-statistic)	0.184429		

GMM: Generalized method of moments

Transit-oriented development (TOD) creates a transportation network that is easily accessible, integrated and oriented toward mass transit facilities. The characteristics of TOD include being integrated with urban centers, pedestrian and bicycle paths, public spaces near stations, and stations designed to be community centers. This is supported by Li et al., (2022) that the existence of a multi-intersection traffic network reduced delay by 44.24% and CO_2 emissions by 2.4%, as well as minimized congestion by 64.33%. Cervero et al. (2004) explained that the joint development of TOD increased accessibility and supported community and regional goals to improve quality of life. This includes improving air quality, preserving open spaces, reducing urban sprawl, and reorienting developmental patterns. Another reason urbanization does not affect emissions is the high educational level of the urban population. The educational facilities available in these areas cause the residents to receive higher knowledge (Pujiati et al., 2017). Furthermore, the existence of higher education changes the community's character and becomes concerned with the environment (Wongphimsorn and Wongchantra, 2021). Pujiati et al. (2020) stated that an individual with a high educational level has excellent environmental literacy and good green consumption behavior.

The national income variable (GDP) results have a positive and significant impact on carbon dioxide. The regression coefficient for the national income variable is 0.004359, which means every US$ 1 billion increase will elevate carbon dioxide by 0.004359 million kilotons. This is in accordance with the EKC hypothesis which describes a positive relationship between economic growth and environmental degradation. The higher the economic growth, the more the environmental emissions. This is because the country will focus on increasing production without paying attention to environmental aspects.

These results are in accordance with Yazdi, S. K., and Dariani, A. G. (Khoshnevis-Yazdi and Shakouri, 2018), who examined 18 countries in Asia from 1980 to 2014 and found that economic growth affected environmental quality. Accordingly, Rahman (2020) investigated the effect of national income on emissions in China, the USA, India, Japan, Germany, Canada, Brazil, South Korea, France, and the UK from 1971-to 2013, showing a positive correlation and significant support for the EKC hypothesis. Economic growth is supported by industrial growth, which causes pollution to increase. A study by Pujiati and Imron (2020) in 30 provinces in Indonesia from 2013 to 2017 stated that industrial developments increase pollution, as evidenced by the significance of the water, air, and land cover quality indexes on GDP.

The EKC hypothesis concept explains the improvements in environmental quality at higher per capita income levels caused by changes in output composition, the introduction of production technology, and demand for quality enhancement, leading to more stringent regulations (Sunday, 2016). This hypothesis explains that environmental damage increases with economic activity up to a certain income level. Furthermore, an increase in income is followed by a better environmental quality (Zilio and Recalde, 2011).

Based on the results in Table 4, the regression coefficient for electricity consumption is 0.304907 with a probability value of 0.0000. This showed a significant and positive relationship between the use of electrical energy and carbon dioxide. Also, the regression coefficient for the use of electrical energy is 0.304907, which means every 1 kWh increase will be followed by an elevation in carbon dioxide of 0.304907 million kilotons, assuming cateris paribus. Therefore, electricity needs to be used with a long-term investment strategy to increase the efficiency of its distribution.

These findings follow Iwata et al. (2010) and Kasperowicz (2015), which showed that energy usage positively and significantly affects CO_2 emissions. Furthermore, Farhani et al. (2014) examined the relationship between emissions and energy use in Tunisia from 1971 to 2008 with the ARDL approach and Granger causality. The results showed that energy use was positively related to CO_2 emissions in the long term. Yang et al. (2012) also stated that energy usage positively correlates with Shanghai's carbon dioxide emissions for the 1978-2010 period. Rahman (2020) further stated that electricity consumption affects carbon emissions in China, the United States, India, Japan, and the United Kingdom.

Based on the results in Table 4, the regression coefficient value of the forest area is -36.14575 with a probability of 0.0849. This showed a negative and significant relationship between forest area and carbon dioxide. The regression coefficient is 36.14575, indicating that every 1-kilometre increase will cause a decrease in CO_2 by 36.14575 with the assumption of ceteris paribus. According to Waheed et al. (2019), increasing forest area can reduce carbon dioxide emissions. Therefore, when a country has a large forest area, a policy is needed to prevent deforestation and be strengthened by law enforcement (Zuhaidha et al., 2014). When there is limited forest land, the country can carry out reforestation engineering by creating vertical gardens in its territory. This aims to plant more trees that absorb CO_2 and improve environmental quality (Ghoustanjiwani et al., 2011; Lestari et al., 2019).

5. CONCLUSIONS AND IMPLICATIONS

This study aims to test the EKC hypothesis in the 10 most populous countries in the world, using CO_2 emissions as the dependent variable and urbanization, national income, electricity consumption, and forest area as the independent. The results showed that national income, electricity consumption, and forest area significantly affect carbon dioxide emissions, which supports the EKC hypothesis. However, urbanization does not affect carbon dioxide release due to an integrated transportation system and the high educational level, which causes environmental literacy. The government now focuses on urban spatial planning by providing services such as public transportation to reduce pollution levels.

An integrated policy regarding urban spatial planning is needed, which is supported by the provision of public facilities to reduce pollution. It is necessary to have a green economic growth policy, which includes industries with minimal pollution and environmentally friendly products that are easy to recycle. Also, efforts to increase the forest areas include reforestation by the vertical garden technique. The limitation of this study is the absence of examination regarding the relationship between educational level and emissions. Therefore, further studies can explore these variables.

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