

Mohd Shahidan Shaari; Noorazeela Zainol Abidin; Abdul Rahim Ridzuan et al.

Article

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Kontakt/Contact

ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: [rights\[at\]zbw.eu](mailto:rights[at]zbw.eu)
<https://www.zbw.eu/>

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The Impacts of Rural Population Growth, Energy use and Economic Growth on CO₂ Emissions

Mohd Shahidan Shaari¹, Noorazeela Zainol Abidin², Abdul Rahim Ridzuan^{2*}, Muhammad Saeed Meo^{3,4}

¹Faculty of Applied and Human Sciences, Universiti Malaysia Perlis, Malaysia, ²Faculty of Business and Management, Universiti Teknologi MARA, Malaysia, ³Department of Management Sciences, Superior University Lahore, Pakistan, ⁴Lab for Gas, Technology and Sustainable Development, RUDN University, Moscow, Russia. *Email: Rahim670@uitm.edu.my

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ABSTRACT

Air pollution can have a repercussion on human health. Economic activity and non-renewable use can lead to pollution. CO₂ emissions are widely used by previous studies as a proxy for environmental degradation. CO₂ emissions exhibit upward trends in most countries including developing countries. The environmental issue has set alarm bells ringing; thus, this study embarks on an investigation into the impacts of energy use, economic growth and rural population growth on CO₂ emissions. The novelty of this study is to explore the impact of rural population growth on CO₂ emissions. The panel ARDL method is employed to analyze data from 1990 to 2015 in 9 selected developing countries with different geographical regions. The results disclose that in the long run, higher energy use and economic growth can increase CO₂ emissions while rural population growth does not cause any change in CO₂ emissions. Rural population growth does not also influence CO₂ emissions in the short run. However, energy consumption and economic growth can be detrimental to the environment in the short run. Therefore, these findings are important for policymakers to formulate policies. More renewable energy sources, such as hydro and biofuel, should be used instead of non-renewable energy sources, such as oil and coal. This can reduce CO₂ emissions.

Keywords: Energy Use, Population, Economic Growth, CO₂ Emissions

JEL Classifications: O11, Q43, Q53, Q56

1. INTRODUCTION

The environment and human health are of utmost importance and therefore we should take them for granted. Hence, the onus is on us to conserve and preserve the environment to ensure sustainable development. In the absence of serious efforts to keep the environment clean, environmental degradation and pollution ensue. It is indisputable that environmental degradation can have deleterious impacts on human health and our ecosystem (Franjic, 2018). Death, diseases, displacement, sickness and disasters caused by environmental degradation have become a common issue in recent years. The World Health Organization (WHO) announced that about 150,000 people died annually stemming from climate change in 2011 and this has set alarm bells ringing in

all countries. Without swift action by all countries, environmental degradation will deteriorate and spiral out of control.

One of the environmental threats to public health is air pollution. According to Ritchie and Roser (2020), air pollution has caused about 5 million deaths in the world. According to a report of the Intergovernmental Panel on Climate Change (IPCC) (2014), greenhouse gas (GHG) emissions are regarded as a serious environmental issue that has long-lasting hazardous impacts worldwide. There are several different types of greenhouse gases. For example, carbon dioxide (CO₂) emissions account for the largest share of total global GHG emissions (Thiri et al., 2017). According to a report published by the Environmental Performance Index (EPI) (2018), environmental problems pertaining to air

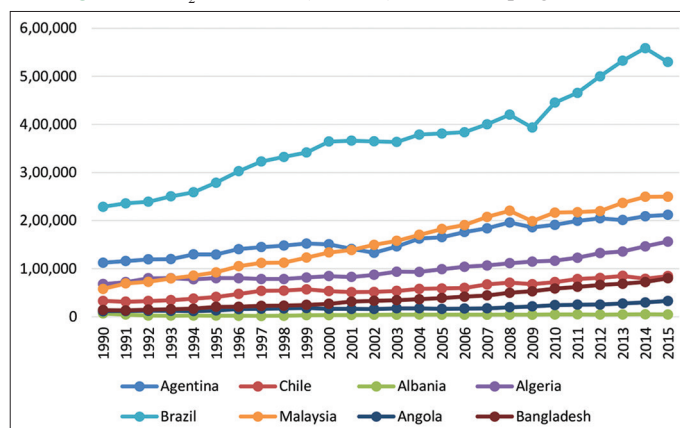
pollution are considered serious and merit attention, especially in newly industrialized countries such as China, Malaysia and India. According to the International Energy Agency (IEA) (2020), the total global CO₂ emissions have risen dramatically by up to 160% from 1990 to 2017. Environmental issues have become more serious especially in Southeast Asia (Baek, 2016; Oktavilia et al., 2017) and in the Association of Southeast Asian Nations (ASEAN) as the countries experience rapid economic growth and great economic transformation. Besides, they also experience the highest economic growth in the world in recent years (Paul and Zhang, 2016). According to the Union of Concerned Scientists (2019), China, India, Japan, Korea and Indonesia contribute 43% of total CO₂ emissions.

Environmental degradation that spirals out of control can lead to health problems. Therefore, the onus is always on us to protect the environment. Nevertheless, some countries especially less developed countries are apathetic about the environmental issues that engulf the world. They turn a blind eye to the issue and thus greater environmental degradation ensues. Their goal to boost economic growth takes precedence over the environment. Energy, particularly non-renewable sources, can have detrimental impacts on the environment. The huge use of fossil fuels can cause various forms of visible and serious damage to the environment (Ridzuan et al., 2018; Nada et al., 2014). According to Ridzuan et al. (2019), Ridzuan et al. (2020a); Ridzuan et al. (2020b), Ridzuan et al. (2021b), Md Razak et al. (2017) and Hezareh et al. (2017), energy use rises CO₂ emissions. However, Belke et al. (2011) and Marinas et al. (2018) argued that energy use should not be reduced as it can disrupt economic growth. Hence, pollution intensifies. Developing countries such as China and India, the most populous countries, move on to boosting their economic activity in no fear of environmental degradation. According to countryeconomy.com (2019), the total global CO₂ emissions exhibited an upward trend from 1970 to 2016 and therefore all countries should play an important role in reducing CO₂ emissions.

Figure 1 shows the total CO₂ (kiloton) emitted by 8 developing countries, particularly Argentina, Chile, Albania, Algeria, Brazil, Malaysia, Angola and Bangladesh. From the figure, it can be seen that Brazil has emitted the largest amount of CO₂ over the period 1990-2015. Brazil's CO₂ emissions went up by as much as 8.6%, reaching its highest amount of CO₂ emitted in 1996, with 302,654 kilotons. In 2009, it went down markedly by 6.4% to 393,331 kilotons. The country that emitted the least amount of CO₂ was Albania. The least amount of CO₂ released by the country was in 2012 with 4,544 kilotons and the largest amount of CO₂ that the country emitted was in 2014 with 5,064 kilotons. All the countries exhibited an overall increasing trend in CO₂ emissions from 2010 to 2015. Bangladesh recorded the largest rise among the 8 developing countries from 2010 to 2015. In 2010, the country emitted 58,539 kilotons of CO₂, but then it drastically went up by as much as 36.8%, reaching 80,091 kilotons in 2015.

Most previous studies have examined the impact of population growth on CO₂ emissions such as Adusah-Poku (2016); Morales-Lage et al. (2016); Saka (2017); and Mikayilov et al. (2017). Other studies such as Ridzuan et al. (20210), Che Sulaiman et al (2021)

Figure 1: CO₂ emissions (kilotons) in 8 developing countries



Source: Countryeconomy.com (2019)

and Abd Rahman et al. (2021) evaluate the impact of population growth on nation debts and economics development. Population growth plays an important role in determining CO₂ emissions. Higher population growth can boost the transportation sector. Therefore, rapid industrialization takes place and thus employment rises. More non-renewable energy sources are inevitably consumed in the residential and commercial sector, transportation sector and industrial sector. Wang et al. (2017) added that a rise in population density can prompt a rise in energy use. If we turn a blind eye to environmental issues that might emerge stemming from population growth, we might be happy with economic growth. However, we must not rule out the negative impact of population growth. However, no attention has been given by previous studies on the impact of rural population growth on CO₂ emissions. Therefore, this study aims to investigate the impacts of energy use, economic growth and rural population growth on CO₂ emissions in selected developing countries (Argentina, Chile, Albania, Algeria, Brazil, China, Malaysia, Angola and Bangladesh). According to Ameen and Mourshed (2017) developing countries face population growth and inability to deal with environmental issues. This study focuses on the rural population due to their use of traditional forms of energy that may lead to environmental degradation. This suggests that most energy consumption in rural areas is inefficient. We chose the 8 developing countries because their trends of CO₂ emissions exhibit a steady increase; thus, serious attention should be given to these countries. Furthermore, the countries are from various continents.

Figure 2 shows the total rural populations in the 8 selected developing countries: Argentina, Chile, Albania, Algeria, Brazil, Malaysia, Angola and Bangladesh from 2010 to 2015. From the figure, it can be learned that Bangladesh has the largest rural population. The population of the other developing countries, namely Argentina, Chile, Albania, Algeria, Brazil, Malaysia, Angola and Bangladesh, exhibited a slow rise over the period. Bangladesh's rural population went up by 0.026% from 102,621,003 in 2010 to 102,647,873 in 2015. Argentina's, Albania's, Algeria's, Brazil's and Malaysia's rural population recorded gradual decreases due to migration to urban areas. The trends in the rural population in the other countries exhibited steady rises. For example, Angola's rural population rose by 8.51% from

9,393,181 in 2010 to 10,192,857 in 2015. Chile's rural population showed a steady rise from 2010 to 2015, with a rise of 65,823.

Figure 3 shows total energy consumption in the 8 developing countries, namely Argentina, Chile, Albania, Algeria, Brazil, Malaysia, Angola and Bangladesh from 2010 to 2015. Energy consumption in those countries exhibits upward trends. Brazil recorded the largest energy consumption over the period with 102,558 ktoe in 2015. Albania recorded the lowest energy consumption over the period with 1136 ktoe in 2015.

Figure 4 shows GDP per capita in the 8 developing countries. GDP per capita in most of the countries remains unstable over the period especially in 2015. It decreased in Chile, Albania, Algeria, Brazil, Malaysia and Angola. However, GDP per capita in Argentina and Bangladesh experienced an increase. In 2015, Argentina had the highest GDP per capita with 13,789 US\$ compared to the other

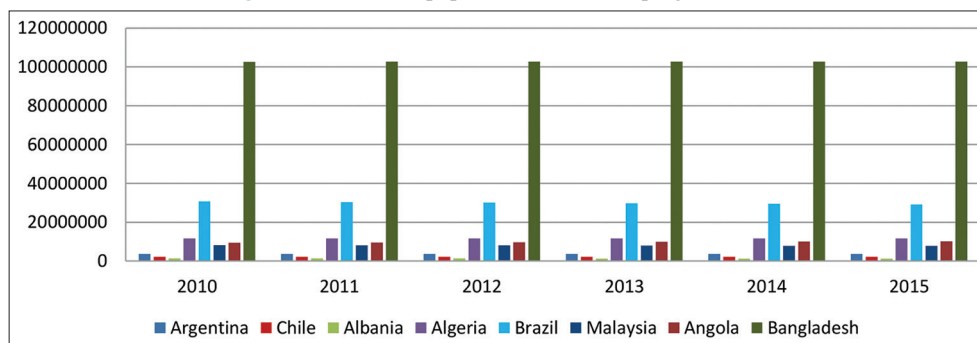
developing countries, and Bangladesh had the smallest GDP per capita with 1248 US\$.

2. LITERATURE REVIEW

The relationship of energy use, economic growth and CO₂ emissions have been explored by numerous previous researchers in various regions such as West Africa (Adewuyi, 2016); Malaysia (Manu and Sulaiman, 2017); and Sub-Saharan (Zaidi and Ferhi, 2019). With a rise in energy use and economic growth in a country, CO₂ emitted by the country is expected to rise simultaneously. Isik et al. (2017) found out that in order to generate economic activity, energy use must escalate. It has been proven by numerous past researchers.

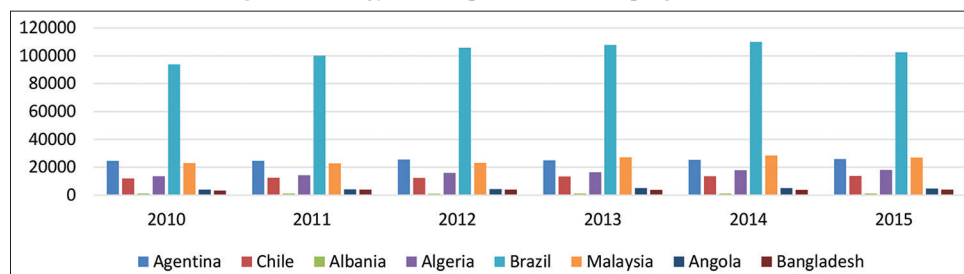
Islam et al. (2017) conducted panel co-integration tests and panel Granger causality approaches. He found that economic growth

Figure 2: Total rural population in 8 developing countries



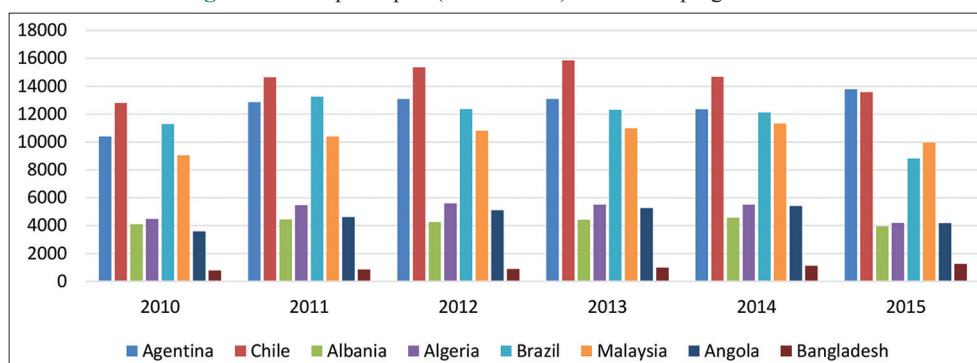
Source: World Bank (2019)

Figure 3: Energy consumption in 8 developing countries



Source: International Energy Agency (2019)

Figure 4: GDP per capita (current US\$) in 8 developing countries



Source: World Bank (2019)

can increase CO₂ emissions and population growth can increase economic growth. Aiyetan and Olomola (2017) obtained slightly different results that in the long run, economic growth can be associated with CO₂ emissions in Nigeria, and in the short run, the results proved that no association between the two variables. In addition, the study also found that energy use and population can positively influence CO₂ emissions in Nigeria. Mohiuddin et al. (2016) also carried out a study on the impacts of energy use and economic growth on CO₂ emissions in Pakistan. The co-integration test, Vector Error Correction Model (VECM) test and Granger causality test were performed and the study found that there is a long-run relationship between energy use, economic growth and CO₂ emissions in Pakistan. Based on VECM, a rise in the production of oil by 1% in Pakistan will rise CO₂ emissions by 13.7% in the long run. The results of the Granger causality test indicated that there is a unidirectional causality relationship running from energy use to CO₂ emissions.

According to a study done by Alam et al. (2015) who tested the EKC hypothesis by employing the same methods (co-integration and Granger causality) to analyze data for a period of 43 years, the study revealed that in India, there is no evidence for the EKC hypothesis. Furthermore, CO₂ emissions cause economic growth. In Indonesia, there is empirical evidence for the EKC hypothesis that energy use has a significant positive relationship with CO₂ emissions. In China, there is evidence for the EKC hypothesis only in the long run, but not in the short run. The EKC hypothesis was proven in both the long run and short run in Brazil. A study by Stamatiou and Dritsakis (2019) with a data period from 1960 to 2011 suggested that there is a strong unidirectional causality nexus between economic growth and CO₂ emission. Moreover, the study also showed that a reduction in energy use is detrimental to the environment and increases economic growth in Italy. From the results shown by previous studies and researches, it can be understood that even though certain countries or regions might not support the EKC hypothesis, the impacts of energy use and economic growth on CO₂ emissions are still fairly obvious in the short run. With a rise in energy use and economic growth, CO₂ emissions will rise subsequently. However, for countries that support the EKC hypothesis, in the long run, a rise in GDP to a certain level will cause a reduction in CO₂ emissions. Studies on energy use, economic growth and CO₂ emissions have been quite common throughout the years. For example, Mustapa and Bekhet (2018) explored the determinants, including energy use and economic growth, of CO₂ emissions. However, studies on the impacts of population, energy use and economic growth on CO₂ emissions are not prevalent, especially in developed countries. The IPAT model introduced by Ehrlich and Holdren (1971) stated that humans at any point of their life can have a certain amount of negative impacts on the environment. It is also hypothesized that population growth in a certain country can prompt environmental degradation. Most previous studies treated CO₂ emissions as an indicator for environmental pollution.

A study by Anser (2019) in Pakistan over the period of 41 years applied the STIRPAT model. The ARDL model and ECM model were employed and the results showed that population growth can significantly raise CO₂ emissions in the country. Ahmed et al. (2016) also showed similar results whereby population growth can

increase CO₂ emissions in the South Asian countries. The panel co-integration method was employed to test the EKC hypothesis. According to Abdulrazaq (2020) who employed co-integration, Dynamics Least Squares (DOLS) and Granger causality found that in Africa, energy use, economic growth and population growth contribute to higher CO₂ emissions. In Ghana, based on a study done by Owusu and Sarkodie (2016), using co-integration, VECM, fit regression model and Granger causality tests, the results revealed that there are long-run equilibrium relationships between economic growth, energy use, population growth and CO₂ emissions. The fit regression model used in the study showed that a 1% rise in population can rise CO₂ emissions by 1.30%. According to Dong et al. (2018) applying the STIRPAT model conducted co-integration and Granger causality tests. The results showed that population growth and economic growth both positively and significantly influence CO₂ emissions. On the other hand, a rise in renewable energy use can help reduce CO₂ emissions. Besides, based on a study by Aye and Edoja (2017) on developing countries using data from 1970 to 2013, their findings revealed that population growth has a positive and significant impact on CO₂ emissions. The dynamic threshold method was employed in the study.

Bekhet and Othman (2017) explored the linkage among urbanization, energy consumption, economic growth, and financial development and CO₂ emissions in Malaysia and found that urbanization can have a significant impact on CO₂ emissions with two different stages. Bekhet et al. (2020) extended the study by reinvestigating the interaction between the environmental Kuznets curve and urban environment transition hypotheses in Malaysia. The results showed that urbanization can have a negative impact on the environment. Based on the review of previous literature it can be seen that there is still a lack of previous studies on the impacts of rural population growth on CO₂ emissions. Thus, it is important for this study to examine the nexus between rural population growth, energy use, economic growth and CO₂ in 8 selected developing countries.

3. METHODOLOGY

This study examines the impacts of energy use, economic growth and rural population growth on CO₂ emissions in 8 selected developing countries from 1990 to 2015. Rural population growth, real GDP and energy use are treated as independent variables while CO₂ emissions are treated as a dependent variable and are a proxy for environmental degradation. It means that higher CO₂ emissions represent higher environmental degradation. Our model specification is adapted from the IPAT model. Thus the model specification is as follows:

$$\ln\text{CO}_{2it} = \beta_0 + \beta_1 \ln\text{GDP}_{it} + \beta_2 \ln\text{E}_{it} + \beta_3 \ln\text{R}_{it} + v_{it} \quad (1)$$

whereas $\ln\text{CO}_2$ represents the log of total CO₂ emissions (ktons), $\ln\text{GDP}$ represents the log of real gross domestic product (GDP) (LCU), $\ln\text{E}$ represents the log of total energy use (ktoe) and $\ln\text{R}$ represents the log of the total rural population. A panel data analysis also requires unit root tests. Unit root tests are conducted to examine the order of integration for all of the variables. Two approaches will be used in this study, namely Im, Pesaran and Shin

W-stat (IPS) and Dickey–Fuller (ADF). The tests are performed for both level and first difference. After performing the panel unit root test, the panel co-integration test will be conducted. This is to determine the existence of the long-run relationship among all the variables. Pedroni (1999), as well as Maddala and Wu (1999), were the first to use this panel co-integration. Pedroni considered the panel co-integration with heterogeneous intercepts and coefficients while Maddala and Wu emphasized the combination of the tests to produce the test statistic for the full panel. The panel co-integration analysis can increase the efficiency of an estimator. Pedroni (1999) proposed two types of statistical tests, namely, panel and group statistics to determine the significance of a panel co-integration test. There are several statistics within dimension, such as panel v- statistic, panel ρ-statistic, panel ρρ-statistic and panel ADF-statistic. The statistics between dimension consists of group ρ-statistic, group ρρ-statistic and group ADF-statistic.

The panel ARDL technique is employed in this study to determine the short-run and long-run nexus between the independent variables and the dependent variable. The panel data analysis is better than time-series data analyses because this study uses 9 countries instead of 1 single country. Moreover, it does not require a large number of years. The ECM is to determine the short-run dynamic. This study chooses to use the panel ARDL method over the Johansen co-integration because it can be employed whether the order of integration is I(0), I(1) or mixed between I(0) and I(1). Three ARDL estimators will be used in this study, namely PMG, MG and DFE. The MG and MG estimators can estimate short-run and long-run coefficients for a large number of years and a large number of countries. However, the PMG estimator cannot estimate long-run coefficients for each country. The DFE estimator does not work well in estimating coefficients for each country. In Equation 2, various lags are included with various variables using the ARDL model. Besides, Equation 3 also provides the short-run and long-run coefficients. The bound test model for the ARDL approach is as follows:

$$Y_{it} = \alpha_{it} + \sum_{j=1}^k \delta_{ij} Y_{j,t-1} + \sum_{i=0}^q \beta'_{it} X_{j,t-i} + \varepsilon_{it} \quad (2)$$

$$\begin{aligned} \Delta \ln \text{CO2}_{it} = & \beta_1 + \sum_{i=1}^k \beta_2 \Delta \ln \text{CO2}_{j,t-i} + \sum_{i=0}^k \beta_3 \Delta \ln \text{GDP}_{j,t-i} \\ & + \sum_{i=0}^k \beta_4 \Delta \ln \text{E}_{j,t-i} + \sum_{i=0}^k \beta_5 \Delta \ln \text{R}_{j,t-i} + \delta_1 \Delta \ln \text{CO2}_{j,t-i} \\ & + \delta_2 \Delta \ln \text{GDP}_{j,t-i} + \delta_3 \Delta \ln \ln \text{E}_{j,t-i} + \delta_4 \Delta \ln \text{R}_{j,t-i} + u_{it} \end{aligned} \quad (3)$$

In Equation 4, $i=1, \dots, n$ is the number of countries, $t=1, \dots, T$ is the number of years and ε is the error term. Δ is the 1st variation factor, and k is the ideal lag length. The model to estimate the long-run impacts of economic growth, energy use and rural population growth on CO₂ emissions is shown in Equation 6. To estimate the short-run impacts, the model is as follows:

$$\begin{aligned} \Delta \ln \text{CO2}_{it} = & \theta_1 + \sum_{i=1}^k \theta_2 \Delta \ln \text{CO2}_{j,t-i} + \sum_{i=0}^k \theta_3 \Delta \ln \text{GDP}_{j,t-i} \\ & + \sum_{i=0}^k \theta_4 \Delta \ln \text{E}_{j,t-i} + \sum_{i=0}^k \theta_5 \Delta \ln \text{R}_{j,t-i} + \theta_5 \text{ECT}_{j,t-i} + e_{it2} \end{aligned} \quad (4)$$

θ_5 is the coefficient of the ECT in Equation 5. It measures the speed of adjustment to equilibrium. The value must be significantly

negative, then we can confirm there is an existence of long-run relationships between the independent variables and the dependent variable. From Equation 6, we can derive Equation 7 as follows to calculate the value of ECT.

$$\begin{aligned} \text{ECT}_{j,t-i} = & \Delta \ln \text{CO2}_{it} - \theta_1 - \sum_{i=1}^k \theta_2 \Delta \ln \text{CO2}_{j,t-i} \\ & - \sum_{i=0}^k \theta_3 \Delta \ln \text{GDP}_{j,t-i} - \sum_{i=0}^k \theta_4 \Delta \ln \text{E}_{j,t-i} - \sum_{i=0}^k \theta_5 \Delta \ln \text{R}_{j,t-i} \end{aligned} \quad (5)$$

4. FINDINGS

Unit root tests have been conducted and the results are reported in Table 1. This study employs Levin, Lin, and Chu (LLC) and IM, Pesaran, and Shin (IPS) to check the stationarity of the data for all the variables (lnCO₂, lnE, lnGDP and lnR). The results of LLC show that all the variables except for lnE and lnR are not significant and thus the null hypothesis cannot be rejected, suggesting that the variables have unit root or are stationary at level. At first difference, the results show that all the variables are significant and therefore, the alternative hypothesis is accepted, implying that the variables used have no unit root or are stationary. The results of LLC are slightly different from the results of IPS. The results of IPS reveal that all the variables are not stationary at level and some of the variables, namely lnCO₂, lnE and lnGDP are stationary at first difference. Based on the results of the unit root tests, a panel ARDL approach can be employed.

Table 2 shows the results of the panel co-integration test from 1990 to 2016. The results show that out of seven statistics, 3 show significance. This means that there is a co-integration relationship among lnCO₂, lnGDP, lnE and lnR. Next, the PMG, MG and DFE estimate tests are conducted.

This study aims to delve into the impacts of rural population growth, economic growth and energy use on CO₂ emissions. Therefore, a panel ARDL method is employed to estimate long-run and short-run coefficients. Table 3 shows the results of long-run estimations using three estimators: PMG, MG and DFE. Two Hausman tests were conducted to determine which estimator is the best. The results of the Hausman tests reveal that PMG is the best estimator as the probability value between PMG and DFE is not significant and the probability value between PMG and MG is also not significant. Based on Table 3, using the PMG estimator, economic growth is found to have a significant effect on CO₂ emissions in the long

Table 1: Panel unit root results

	Im, Pesaran and Shin W-stat (IPS)		Augmented Dickey–Fuller (ADF)	
	Level	1 st Difference	Level	1 st Difference
lnCO ₂	1.3105 (0.9050)	−7.9430* (0.0000)	15.6351 (0.4787)	89.6057* (0.0000)
lnE	0.5505 (0.7090)	−8.1051* (0.0000)	17.7498 (0.3387)	89.2261* (0.0000)
lnGDP	3.7158 (0.9999)	−7.4851* (0.0000)	10.4397 (0.8427)	80.9210* (0.0000)
lnR	−0.4435 (0.3287)	−4.2415* (0.0000)	38.9778* (0.0011)	54.3435* (0.0000)

* and** show the significance levels of 1% and 5%, respectively. The values in parenthesis are the probability values

Table 2: Panel co-integration results

Alternative hypothesis: common AR coefs. (within-dimension)		
	Statistic	Prob.
Panel v-statistic	-0.2068	0.5819
Panel rho-statistic	-0.3845	0.3503
Panel PP-statistic	-3.6786*	0.0001
Panel ADF-statistic	-2.2637**	0.0118
Alternative hypothesis: common AR coefs. (between-dimension)		
	Statistic	Prob.
Group rho-statistic	0.5171	0.6975
Group PP-statistic	-2.6592*	0.0039
Group ADF-statistic	-1.2470	0.1062

* and** show the significance levels of 1% and 5%, respectively

Table 3: Long-run estimation results

Variable	PMG		MG		DFE	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
lnGDP	0.2893*	0.004	0.3568	0.076	0.7869*	0.000
lnE	0.9468*	0.000	0.7678*	0.002	0.1460	0.423
lnR	-0.4975	0.086	1.4178	0.200	-0.3575	0.324
Hausman	2.04	0.5634			0.00	1.00

* shows the significance level of 1%

Table 4: Short-run estimation results

Variable	PMG		MG		DFE	
	Coefficient	Prob.	Coefficient	Prob.	Coefficient	Prob.
ECT	-0.2464*	0.002	-0.5656*	0.000	-0.1571*	0.000
lnGDP	0.4892*	0.000	0.0026	0.995	0.3465*	0.000
lnE	0.1705*	0.010	0.0239	0.665	0.3610*	0.000
lnR	4.0577	0.188	4.6059	0.117	-2.1848**	0.012
C	0.4124*	0.001	-14.8661	0.170	-1.1129	0.395
Hausman	2.04	0.5634			0.00	1.00

* and** show the significance levels of 1% and 5%, respectively

Table 5: Granger causality results

Independent Variable	Dependent Variable [F-statistic]			
	lnCO ₂	lnGDP	lnE	lnR
lnCO ₂	-	3.43507** (0.0343)	4.4348** (0.0131)	0.7653 (0.4667)
lnGDP	8.0825* (0.0004)	-	6.28089* (0.0023)	1.59459 (0.2057)
lnE	0.4459 (0.6409)	1.7498 (0.1766)	-	1.1870 (0.3074)
lnR	2.2313 (0.1102)	0.4208 (0.6572)	1.5399 (0.2171)	-

* and** show the significance levels of 1% and 5%, respectively. The values in parenthesis are the probability values

run. This means that an increase in economic growth can cause environmental degradation to intensify. The results of DFE confirm the significant effect of economic growth on CO₂ emissions. However, the results of MG show no significant impact of economic growth on CO₂ emissions. Based on the results of PMG and MG, energy consumption can influence CO₂ emissions in the long run. This can be inferred that higher energy consumption can release more CO₂. However, the results of DFE show no significant effects of energy consumption on CO₂ emissions. These results are not consistent with the results of DFE. The results of DFE disclose that energy consumption does not influence CO₂ emissions in the long run. The results of all the estimators (PMG, MG and DFE) consistently reveal that rural population growth does not influence CO₂ emissions in the long run.

Table 4 reports the results of short-run estimations using three estimators: PMG, MG and DFE. The error correction terms are significant and negative for all the estimators. This confirms that there are long-run relationships among economic growth, energy consumption, rural population growth and CO₂ emissions. In the short run, the results of PMG and DFE prove that economic growth can influence CO₂ emissions. This suggests that economic growth can cause more environmental degradation in the short run. However, the results of MG do not show any significant impact of economic growth on CO₂ emissions. The results of PMG and DFE consistently indicate that CO₂ emissions are associated with energy consumption in the short run. This indicates that higher energy consumption can be detrimental to the environment in the short run. The results of MG show no significant impacts of energy consumption on CO₂ emissions. The results of PMG and MG show that rural population growth does not have any influence on CO₂ emissions in the short run. This means that rural population growth does not have any deleterious impact on CO₂ emissions in the short run

Table 5 shows the results of Granger causality. From the table, it can be learned that there is a bidirectional relationship between

economic growth and CO₂ emissions. The results also show that there is a unidirectional relationship running from CO₂ emissions to energy consumption. It is found that there are no causal relationships between energy consumption and rural population growth, economic growth and rural population growth, and energy consumption and population growth.

Table 6 reports the impacts of economic growth, energy consumption and rural population growth on CO₂ emissions in all of the selected developing countries (Albania, Algeria, Angola, Argentina, Bangladesh, Brazil, Chile and Malaysia). The results are based on the PMG estimator as it is the most appropriate estimator in this study. From the table, it can be learned that economic growth can positively influence CO₂ emissions in Algeria, Argentina, Brazil and Malaysia. Economic growth does not exhibit any significant impact on CO₂ emissions in the other countries (Albania, Angola, Bangladesh and Chile).

From the table, we can see that economic growth in Algeria has the largest impact on CO₂ emissions as its coefficient value is 0.9642 compared to the other developing countries. This suggests that a 1% rise in economic growth leads to a 0.96% rise in CO₂ emissions in the short run in Algeria. We can also learn that Argentina exhibits the smallest impact of economic growth on CO₂ emissions. The coefficient value is 0.2699 and this indicates that economic growth goes up by 1%, then CO₂ emissions will rise by 0.27%. Other than that, energy consumption can significantly and positively influence CO₂ emissions in Argentina, Bangladesh and Brazil. The impact of energy consumption on CO₂ emissions in Brazil is larger than the impact in Argentina and Bangladesh. However, there is no impact of energy consumption on CO₂ emissions in most of the developing countries, namely Albania, Algeria, Angola, Chile and Malaysia. The findings also show that rural population growth can positively and significantly impact CO₂ emissions in Albania, Algeria and Malaysia. On the other hand, the other developing

Table 6: Short-run estimation results for each country

	lnE	lnGDP	lnR	C
Albania	0.0840 (0.628)	0.2320 (0.322)	23.3653* (0.002)	1.0508 (0.758)
Algeria	0.1979 (0.085)	0.9642* (0.001)	5.2968* (0.000)	0.2331 (0.676)
Angola	0.0723 (0.392)	0.0310 (0.830)	7.5102 (0.139)	-0.1055 (0.596)
Argentina	0.2885** (0.027)	0.2699** (0.019)	-0.6876 (0.778)	0.4135 (0.694)
Bangladesh	0.2386 ** (0.011)	0.9178 (0.490)	-3.8625 (0.369)	0.4612 (0.615)
Brazil	0.4752** (0.024)	0.4826** (0.040)	-1.6067 (0.079)	0.3633 (0.689)
Chile	0.1811 (0.507)	0.3795 (0.217)	-1.3153 (0.375)	0.1246 (0.972)
Malaysia	-0.1738 (0.110)	0.6363* (0.000)	3.7614** (0.023)	0.7588 (0.645)

* and** show the significance levels of 1% and 5%, respectively

countries, particularly Angola, Argentina, Bangladesh, Brazil and Chile show no significant impact of rural population growth on CO₂ emissions in the short run.

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6. CONCLUSION

This study aims to examine the impacts of energy use, rural population growth and economic growth on CO₂ emissions in 8 selected countries (Albania, Algeria, Angola, Argentina, Bangladesh, Brazil, Chile and Malaysia). The ARDL approach is employed to analyze data from 1990 to 2015 and the results disclose that overall, energy use plays an important role in increasing CO₂ emissions in the long run and this finding is similar to Aiyetan and Olomola (2017) and Mohiuddin et al. (2016). Higher energy use can cause higher environmental degradation. The results also reveal that economic growth can increase CO₂ emissions in the long run. These findings are consistent with the findings of Abdulrazaq (2020). This means that economic activity can result in environmental degradation. Rural population growth does not have any impact on CO₂ emissions in the long run.

In the short run, overall economic growth and energy use can result in higher CO₂ emissions. These results are similar to most previous studies such as Hossain (2012), Ibrahim (2015) and Alkhathlan and Javid (2015). Overall rural population growth does not lead to any change in CO₂ emissions in the short run. The results of the Granger causality test show that there is a bidirectional relationship between economic growth and CO₂ emissions. The results also show that there is a unidirectional relationship running from CO₂ emissions to energy consumption. Specifically, more energy consumption can cause CO₂ emissions to escalate in some developing countries, such as Argentina, Brazil and Bangladesh. Economic growth can result in higher CO₂ emissions in Algeria,

Argentina, Brazil and Malaysia. Other than that, rural population growth can have a deleterious impact on CO₂ emissions in Albania, Algeria and Malaysia.

These findings will shed light on the environmental issue and thus will help policymakers formulate policies. Energy diversification policies should be introduced or improved so that the developing countries use more renewable energy sources, such as hydro, solar and biodiesel. Owusu and Sarkodie (2016), Sinha et al. (2017) as well as Majeed and Luni (2019) proposed that more renewable energy sources should be consumed to satisfy our needs in order to reduce non-renewable energy sources, such as oil, gas and coal. Thus, environmental degradation can be reduced. The government policymakers need to attract more foreign direct investment from advance country as FDI could be possibly lead towards environmental sustainability as reported by Ridzuan et al. (2017), Ridzuan et al. (2018b) and Ridzuan et al. (2018c). Gierzynski et al. (2016) and Vija Kumaran et al. (2020) stated that renewable energy is a more environmentally friendly alternative compared to fossil fuel. Other than that, tax relief can be imposed on green technology imports (Bekhet and Othman, 2018). Therefore, it will encourage them to emit more CO₂ that can harm the environment. If they still want to emit more CO₂, they have to pay the governments, and thus the governments' revenues will rise.

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