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REVISITING THE ENERGY CONSUMPTION, ECONOMIC GROWTH AND THE ENVIRONMENTAL KUZNETS CURVE IN DEVELOPING COUNTRIES[1]

Abstract. Though economic development improves human lives and living standards, it poses serious environmental challenges. In recent decade, this has attracted the attention of researchers and policymakers aiming to find a balance between economic development and environment quality. The study examines the long and short-run effects of renewable energy, non-renewable energy, economic growth (gross domestic product) and carbon dioxide (CO_2) emissions in 16 developing countries. Using a panel dataset from 1990 to 2020, we tested the Environmental Kuznets Curve (EKC) by employing the pooled mean group (PMG) and Mean group (MG) estimators. The empirical results provide evidence of a positive long and short-run nexus between economic development and environmental degradation when environmental degradation is made the dependent variable, confirming the EKC hypothesis. However, when economic development is made the dependent variable, the result elucidates the existence of the negative long and short-run effects. Further, whereas renewable energy abates environmental degradation in both the long and short run, it promotes economic development in both periods. Finally, non-renewable energy increases environmental degradation in both the long and short run but promotes economic development only in the long run. Based on the findings of the study, we provide potential policy measures that can help to improve the environmental quality.

Keywords: Environmental degradation, renewable energy, non-renewable energy, economic development, PMG estimator, MG estimator

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ИССЛЕДОВАТЕЛЬСКАЯ СТАТЬЯ

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Потребление энергии и экономический рост в развивающихся странах в контексте экологической кривой Кузнеца

Аннотация. Экономическое развитие не только приводит к повышению качества жизни населения, но и создает серьезные экологические проблемы. Как ученые, так и политики стремятся найти баланс между экономическим развитием и качеством окружающей среды, особенно в последнее десятилетие. В настоящем исследовании рассматривается взаимосвязь между возобновляемыми и невозобновляемыми источниками энергии, экономическим ростом (выраженным через валовой внутренний продукт) и выбросами углекислого газа (CO_2) в 16 развивающихся странах в краткосрочной и долгосрочной перспективе. На основе панельных данных за период с 1990 г. по 2020 г. авторы оценили экологическую кривую Кузнеца, применив методы сводных групповых средних и групповых средних. Полученные результаты свидетельствуют о долгосрочной и краткосрочной положительной связи между экономическим развитием и ухудшением состояния окружающей среды, когда ухудшение состояния окружающей среды является зависимой переменной, что подтверждает гипотезу о наличии экологической кривой Кузнеца. Однако когда экономическое развитие выступает в качестве зависимой переменной, возникают долгосрочные и краткосрочные отрицательные эффекты. Кроме того, применение возобновляемых источников энергии приводит к снижению деградации окружающей среды как в долгосрочной, так и в краткосрочной перспективе, а также способствуют экономическому развитию в обоих периодах. Наконец, использование невозобновляемых источников энергии усиливает деградацию окружающей среды как в долгосрочной, так и в краткосрочной перспективе, но содействует экономическому развитию только в долгосрочной перспективе. Исходя из результатов исследования были сформулированы рекомендации и предложены меры по улучшению качества окружающей среды.

Ключевые слова: деградация окружающей среды, возобновляемая энергия, невозобновляемая энергия, экономическое развитие, метод сводных групповых средних, метод групповых средних

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Introduction

The aim of this research is to explore the intricate relationship among renewable and non-renewable energy sources, economic progress measured by GDP, and carbon dioxide (CO_2) emissions, while also examining whether the environmental Kuznets curve exists. Even though economic development contributes to enhancing people's lives and well-being, it also poses significant environmental issues. In fact, studies have shown that economic growth results in a 1.4 % surge in overall emissions (Al Smadi & Bekhet, 2017; Bekhet & Othman, 2018). In recent decades, the levels of atmospheric CO_2 emissions have more than doubled from the pre-industrial era, leading to severe global warming events and environmental degradation (Dogan & Ozturk, 2017). Anthropogenic activities have been identified as the major cause of the increase in atmospheric CO_2 emissions (Boukhelkhal, 2021). Therefore, it is crucial to adopt sustainable environmental policies that can address the issue of environmental degradation while also promoting economic development. However, since economic development is the primary objective of every nation, environmental policies must be balanced against economic growth to strike a harmonious relationship between the two.

Based on the perspective of Ulucak et al. (2020), we posit that economic growth's effect on environmental degradation can be divided into two categories. The first is through over-utilisation of natural resources and the heightened demand for residential and agricultural lands, leading to deforestation and more raw material utilisation for industrial purposes, resulting in waste generation (Ulucak et al., 2020). Nevertheless, it is argued that integrating rigorous environmental sustainability principles into national economic procedures could mitigate the adverse environmental impact, which can be achieved through technological innovation and shifting towards resource-efficient production and consumption. The second category of environmental degradation caused by economic growth is via greenhouse gas emissions due to the surge in energy demand and consumption (Ulucak et al., 2020). Energy consumption is considered a vital component of economic development (Wang et al., 2018), and the relationship between energy consumption and economic growth has been extensively examined (Ahmed et al., 2016; Dogan & Ozturk, 2017; Ma et al., 2021; Muhammad et al., 2014). To curb the negative impact of non-renewable energy on environmental degradation, most scholars are advocating for a transition from fossil fuels to renewable energy sources (Bhat, 2018; Wang et al., 2018). In fact, while primary energy consumption decreased by 4.5 % in 2019, mainly due to fossil fuels, renewable energy consumption increased by approximately by 10 %[1].

The aforementioned indicates that energy consumption, whether from renewable or non-renewable sources, has distinct effects on economic development and environmental degradation. Therefore, it is crucial to comprehend not only the impact of economic growth on environmental degradation but also the effect of CO_2 on economic growth during the transition from non-renewable to renewable energy. This study examines the interrelationships among the aforementioned variables within the context of specific African countries, with the added significance of being among the first to consider the concurrent effect of economic growth and carbon emissions while factoring in the role of energy consumption in the selected countries.

To contribute to the ongoing discourse, this study accomplishes the following objectives: (1) investigates the short-term and long-term relationships between economic development, renewable energy, non-renewable energy, and environmental degradation; (2) explores the effect of the short-term and long-term relationships between environmental degradation, renewable energy, non-renewable energy, and economic development; and (3) assesses the existence of the environmental Kuznets curve.

The remaining sections of this paper are organised as follows: Section 2 presents a review of the relevant literature, section 3 outlines the research methodology, section 4 presents and discusses the results, and section 5 summarises the findings and provides policy recommendations.

2. Literature Review

Several studies in the literature have investigated the factors contributing to environmental degradation worldwide, including studies by Cherni and Essaber Jouini (2017), Espoir et al. (2022), Ito (2017), Mahmood et al. (2019), and Rehman et al. (2019). These studies have assessed three strands of research.

The first strand has explored the relationship between economic development and environmental degradation by testing the environmental Kuznets curve. For example, He and Richard (2010) reported a positive impact of economic development on environmental degradation in Cambodia, but they were unable to confirm the presence of the environmental Kuznets curve. Aslam et al. (2021) used data from 1971 to 2016 to demonstrate a positive effect between economic development and environmental degradation in Malaysia and confirmed the presence of the environmental Kuznets curve. Similarly, Saboori et al. (2012) discovered a long-term link between economic development and environmental degradation, as well as an inverted U-shape correlation between the two variables in Malaysia when they used data from 1980 to 2009. Finally, using data from 1980 to 2016 on African countries, Boukhelkhal (2021) found a positive correlation between economic growth and environmental degradation and confirmed the environmental Kuznets curve hypothesis. In their analysis of a dataset from 1970 to 2014 in Myanmar, Aung et al. (2017) discovered both a short and long-term correlation between economic growth and environmental degradation, confirming the U-shaped hypothesis.

Another category of studies has examined the connection between renewable energy and environmental degradation. For example, Apergis et al. (2010) used the panel error correction model to investigate the relationship between renewable energy and environmental degradation in both developed and developing countries from 1984 to 2007. They discovered that nuclear energy reduces emissions, while renewable energy has a positive correlation with emissions. Menyah and Wolde-Rufael (2010) investigated the relationship between renewable energy and CO_2 emissions in the United States from 1960 to 2007 and found that nuclear energy reduces emissions, while no statistical significance was found for renewable energy. A regional study in Africa using data from 1980 to 2018 found that renewable energy promotes emission reduction (Menyah & Wolde-Rufael, 2010). In G7 countries, Nathaniel et al. (2021) used a dataset from 1990 to 2017 to investigate the relationship between renewable energy and CO2 emissions and discovered that nuclear energy reduces emissions, while renewable energy was not statistically significant.

Finally, the third category of studies investigated the interactions between non-renewa-

[1] BP Energy outlook. (2021). Statistical Review of World Energy globally consistent data on world energy markets and authoritative publications in the field of energy. BP Energy Outlook 2021, 70, 8–20. Retrieved from: https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html.

ble energy and CO2 emissions. Nathaniel et al. (2021) conducted a study in Turkey using data from 1970 to 2013 to investigate the correlation between non-renewable energy and CO2 emissions and reported a positive relationship between these two variables. Meanwhile, a study conducted in Thailand from 1971 to 2013 revealed that non-renewable energy sources promote emissions. In Russia, Anufriev (2006) conducted an economic and environmental assessment of energy resources and developed an energy-saving roadmap. Although there have been many studies examining the environmental relationship between the variables of interest, the literature has not yielded conclusive findings. Therefore, further research is necessary, particularly in developing countries where non-renewable energy sources are widely used for economic activities. Radmehr et al. (2022) applied the GMM model to investigate the impact of energy consumption on carbon emissions in G7 countries using data from 1990 to 2018 and found that renewable energy mitigates emissions. Similarly, Ali et al. (2022) examined the effect of renewable energy on carbon emissions in South America from 1995 to 2020 using a series of econometric methods and found that renewable energy consumption reduces emissions. In another study, Ali and Amfo (2021) compared the economic and ecological values of selected countries from 1960 to 2018 and concluded that renewable energy consumption leads to a decrease in carbon emissions. Finally, Ali and Anufriev (2020) explored the causal relationship between fossil fuels and emissions in Ghana using data from 1975 to 2014 and found that fossil fuels exacerbate carbon emissions.

3. Materials and Methods

3.1. Data Description

The study employed a time-series dataset from 16 developing economies spanning 1990 to 2020 (Table 2). We utilised the autoregressive distributed lag (ARDL) as the main framework for our data analysis as specified below:

$$\Delta g_{s,t} = \sum_{j=1}^{p-1} \gamma_{j,s} \Delta g_{s,t-j} + \sum_{j=0}^{q-1} \delta'_{j,s} \Delta x_{s,t-j} + +\varphi_s \left[g_{s,t-1} - \theta_{0,s} - \theta'_{1,s} x_{s,t} \right] + \varepsilon_{st}, \quad (1)$$

where $\gamma_{j,s}$ and $\delta_{j,s}$ denotes short-run coefficients, $\theta_{0,s}$ and $\theta_{1,s}$ denotes long-run coefficients, and φ_s is the speed of adjustment (error-correction term) to the long-run equilibrium, g denotes the CO_2 emissions, x denotes the covariates, s and t denote the country and time, respectively.

Table 1

Descriptive statistics

Variable	CO_2 Per capita	GDP per capita	Renewable energy	Non-renewable energy
Mean	8.75	10.44	18.26	2.69
Std dev	0.72	0.13	6.26	4.09
Min	6.65	10.18	3.56	0.07
Max	10.91	10.75	94.37	15.48

Source: Author's calculation.

Table 2

List of 16 Developing countries considered for the study

Ghana	Senegal	Cameroon
Nigeria	Botswana	Tanzaia
Cote d'Ivoire	Algeria	South Africa
Burkina Faso	Mali	Zambia
Kenya	Angola	
Egypt	Tunisia	

The advantages of using the ARDL method in the form of the error correction are highlighted by Pesaran and Smith (1995), Johansen (1995), Pesaran et al. (1999), and Philip and Hansen (1990). Nonetheless, the choice between the pooled mean group (PMG) and mean group (MG) models requires a trade-off between efficiency and consistency (Alam & Murad, 2020).

It is important to note that environmental degradation, which is proxied as CO_2 emissions measured in metric tonnes per capita, and economic development, which is proxied as gross domestic product (GDP) per capita measured in constant 2010 US$, are the variables of interest in this study. Renewable energy is measured as a percentage of total energy consumption, while non-renewable energy is measured as kg of oil equivalent per capita. All the variables are obtained from the World Development Index (WDI) database. Tables 1 and 2 present the descriptive statistics of the study variables and the list of countries considered in the study. In the subsequent stage of the analysis, a correlative analysis is conducted to examine the relationships between the study variables (Table 3). The results indicate a significant positive association between environmental degradation and economic development, as well as between environmental degradation and renewable energy. On the other hand, a significant negative relationship is observed between environmental degradation and non-renewable energy. Additionally, economic development is significantly and positively related to both renewable and non-renewable energy. However, no statistically significant relationship is found between renewable and non-renewable energy.

Table 3

Correlation analysis

Variable	$LnCO_2$ Per capita	LnGDP per capita	LnRenewable energy	LnNon-renewable energy
$LnCO_2$ Per capita	1			
LnGDP per capita	0.539***	1		
LnRenewable energy	0.392***	0.200***	1	
LnNon-renewable energy	–0.074***	0.419***	0.24	1

Note: *** significance at the 1 % levels
Source: Author's calculation.

Table 4

Unit Roots tests

	IPS		LLC		Order of Integration
	level	1st difference	level	1st difference	I(1)
$LnCO_2$ Per capita	–0.96	–2.46***	–6.32	–1.95***	I(1)
LnGDP per capita	–0.75	–12.40***	–4.76	–6.12***	I(1)
LnRenewable energy	–1.39	–3.87***	–3.91	–1.62***	1(1)
LnNon-renewable energy	0.013	–4.58***	–5.14	–4.14***	I(1)

Note: *** significance at the 1 % levels.
Source: Author's calculation.

3.2. Test of Unit Root and Panel Cointegration

In this study, we analysed the short and long-term relationships between the variables of interest by testing for the presence of unit roots in the data. To conduct this test, we used two different methods: the Im-Pesaran-Shin (IPS) (Im et al., 2003) and the Levin, Lin, Chu (LLC) (Levin et al., 2002). The null hypothesis in this case states that all variables have unit roots, while the alternative hypothesis is that they do not. The results of the unit roots tests are presented in Table 4, which shows that at level, all variables are not stationary in the IPS and LLC tests. However, once the first differences of variables are taken, all the variables become stationary at the order I(1). This suggests that all variables are integrated of order I(1).

After determining the order of integration, the researchers performed a panel cointegration test based on the Kao tests. The results of the Kao tests of cointegration are presented in Table 5, which provides evidence that the null hypothesis of no cointegration is rejected for all the covariates at a 1 % significance level. This indicates that there is a presence of cointegration.

Table 5

Kao cointegration test

Tests	Statistic	*p*-value
Kao test		
Modified Dickey-Fuller *t*	–2.06	0.000***
Dickey-Fuller *t*	–3.74	0.000***
Augmented Dickey-Fuller *t*	–1.31	0.076***
Unadjusted modified Dickey-Fuller *t*	–1.19	0.052***
Unadjusted Dickey-Fuller *t*	–3.73	0.000***

Note: *** significance at the 1 % levels.
Source: Author's calculation.

3.3. The Pooled Mean Group (PMG) and Mean Group (MG) Estimators

The PMG estimation method, as described by Pesaran et al. (1999), permits short-term variations to differ across panels, while restricting long-term slope coefficients to remain the same across panels. The intercepts, short-run coefficients, and error variances, on the other hand, are allowed to vary across groups. To ensure consistency and efficiency, the covariates must be exogenous, meaning they must not be serially correlated, and both the dependent and independent variables must include lags.

In contrast, the MG estimator enables the estimation of country-specific regressions by considering each country coefficient as an unweighted mean of the individually estimated coefficient. This method has a more flexible estimation procedure since it does not impose limitations on variations in coefficients in both periods. However, a large number of panels is required to satisfy the validity and consistency requirements cited by Pesaran et al. (1999) and Alam & Murad (2020).

3.4. The Hausman Test

To evaluate the relative merits of the three models, the Hausman test is utilised to test for significant differences among them. The test assumes that there are no significant differences between the PMG and MG models. If there is no significant difference, then the null hypothesis is justified and the PMG model is selected. However, if there is a significant difference, the alternative hypothesis is supported, and the MG model is preferred. This procedure is applied to test for differences between the MG and PMG models.

4. Results and Discussion

4.1. Environmental Impact Assessment

In order to achieve the objectives of the study, a series of economic procedures were conducted prior to estimating the main models. We proceeded with estimating both the PMG and MG models to determine the short and long-run effects between the variables under investigation. The results are presented in Table 6. However, considering the strengths and weaknesses of the two models, the Hausman test was performed to determine which model is the most appropriate for the study. The test yielded a p-value of 0.931, indicating a preference for the PMG model over the MG model. Nevertheless, results from both models are presented for comparison purposes, and the error correction (ECT) is provided to demonstrate the speed at which the series reverts to equilibrium.

The PMG estimates reveal that economic development has a significantly positive effect on environmental degradation in both the short and long run at a significance level of 5 %. Specifically, the results suggest that a 1 % increase in economic development will result in a 0.033 % and 0.021 % increase in environmental degradation in the long and short term, respectively. Similarly, the MG estimates show that a 1 % increase in economic development has a significant positive effect on environmental degradation in the long run, but no evidence of a short-run effect was found. These findings align with those of previous studies such as Ali and Anufriev (2020), Bölük and Mert (2015), and Polloni-Silva et al. (2021).

In the PMG estimation, the long-run effect of the square of economic development on environmental degradation is found to be significantly negative at a 10 % level of significance. However, there is no significant effect in the short run (as seen in the PMG estimator). This suggests that an increase in the square of economic development will result in a 0.026 % decline in environmental degradation in the long run. On the other hand, the MG estimator did not find any statistically significant effects for both short and long-run effects. The significant negative effect of the square of economic development suggests the presence of an environmental Kuznets curve, which indicates an inverted U-shaped relationship between economic development and environmental degradation. This finding is consistent with the research of Boontome et al. (2017) who suggested that environmental degradation decreases beyond a certain level of economic development.

In terms of renewable energy, the PMG estimator revealed a statistically significant negative effect in the long and short run, with a significance level of 1 %. This suggests that an increase in renewable energy will lead to a decrease of 0.074 and 0.021 in environmental degradation in the long and short term, respectively. The MG estimator also indicates a significant negative effect between renewable energy and environmental degradation in both the long and short run, which is

Table 6

PMG and MG results for the impact on environmental pollution

	PMG		MG	
	Long-term	**Short-term**	**Long-term**	**Short-term**
Dependent variable = $\ln CO_2$ Per capita				
LnGDP per capita	0.033** (0.059)		0.004** (0.176)	
LnGDP per capita square	−0.026*(0.014)		–0.022(0.57)	
LnRenewable energy	−0.074***(0.050)		–0.185*(0.076)	
LnNon-renewable energy	0.032***(0.124)		0.078*(0.048)	
ECT	−0.052***(0.313)		–0.005***(0.069)	
LnGDP per capita		0.021**(1.074)		– 0.103(0.100)
LnGDP per capita square		0.006(0.012)		0.084 (0.034)
LnRenewable energy		−0.021***(0.124)		–0.327***(0.035)
LnNon-renewable energy		0.167*** (0.616)		0.413**(0.247)
Constant		0.317***(0.321)		1.963***(0.952)
Hausman test		5.174@		
p-value		0.931		

Note: *, ** and *** respectively, significance at the 5 % and 1 % levels. Standard errors in parentheses. @ shows comparison between PMG with MG.
Source: Author's calculation.

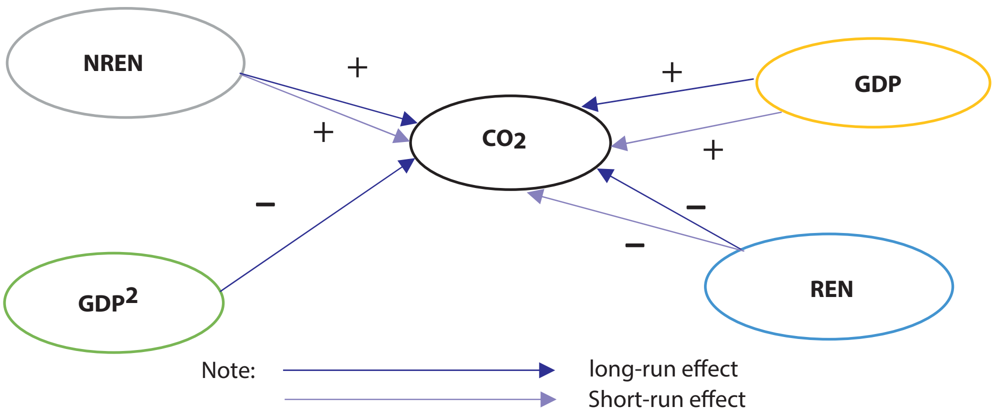

Fig. 1. *Relationship between the independent variables and environmental degradation in developing countries*

consistent with the findings of Bölük and Mert (2015) and Polloni-Silva et al. (2021).

On the other hand, the PMG estimator shows that non-renewable energy has a positive effect on environmental degradation, with a 1 % level of significance in both the long and short run. Specifically, an increase in non-renewable energy would lead to an increase of 0.32 % and 0.167 % in environmental degradation in the long and short run, respectively. Under the MG estimator, non-renewable energy promotes environmental degradation with a significance level of 10 % in the long run and 5 % in the short run. This finding is consistent with Nathaniel & Iheonu (2019). Figure 1 provides a summary of the long and short-run relationship between the variables.

4.2. Economic Impact Assessment

Table 7 presents the results of the study's evaluation of the impact of variables when economic development is the dependent variable. The preferred model according to the Hausman test is the PMG estimator. The results indicate that environmental degradation has a negative relationship with economic development in the long run and short run, with statistical significance at the 1 % and 10 % levels, respectively. In the short run, a 1 % increase in environmental degradation leads to a 0.072 % decrease in economic development, while in the long run, a 0.041 % decrease in economic development is caused by a percentage increase in environmental degradation. This could be due to the significant impact of CO_2 emissions, which primarily affects the economic development sectors in developing countries. The MG estimator shows a negative long-run effect of environmental degradation, but the short-run effect is insignificant.

Moreover, the PMG estimator reveals a positive and significant coefficient of renewable en-

Table 7

PMG and MG results for the impact on economic development

	PMG		MG	
	Long-term	**Short-term**	**Long-term**	**Short-term**
Dependent variable = LnGDP per capita				
$\ln CO_2$ Per capita	-0.041^{***}(0.041)		-0.053^{*}(0.027)	
$\ln CO_2$ per capita square	0.201(0.043)		0.802(0.109)	
LnRenewable energy	0.069^{*} (0.138)		0.145(0.274)	
LnNon-renewable energy	0.0103^{***}(0.032)		−0.341(0.336)	
ECT	-0.042^{***}(0.011)		-0.098^{***}(0.020)	
$\ln CO_2$ Per capita		-0.072^{*}(0.063)		−0.008(0.095)
$\ln CO_2$ per capita square		−087(0.155)		0.098(0.401)
LnRenewable energy		0.020^{***}(0.046)		0.013^{***}(0.306)
LnNon-renewable energy		0.019(0.080)		-0.047^{**}(0.0182)
Constant		0.982^{***}(0.321)		0.534^{***}(0.952)
Hausman test		7.035@		
p-value		1.000		

Note: *, ** and *** respectively, significance at the 5 % and 1 % levels. Standard errors in parentheses. @ shows comparison between PMG with MG.
Source: Author's calculation.

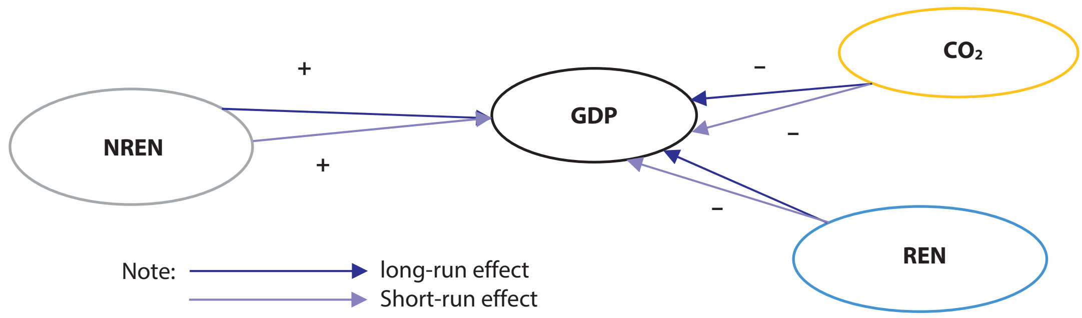

Fig. 2. *Relationship between the independent variables and economic development in developing countries*

ergy, with significance levels of 10 % and 1 % in the long and short-run, respectively. This suggests that a percentage increase in renewable energy results in a corresponding increase in economic development by 0.069 % and 0.020 % in the short and long run, respectively. Conversely, although the short-run effect is positive under the MG, the long-run effect is insignificant.

Finally, the PMG estimator shows that non-renewable energy has a positive and statistically significant effect on economic development in the long run at a 1 % level of significance, indicating that non-renewable energy promotes economic growth in the long run. However, the MG estimator has a negative impact on economic growth in the short run. The summary of the long and short-run effects is presented in Figure 2.

5. Conclusion and Recommendations

The study explored the relationship between renewable energy, non-renewable energy, economic growth (GDP) and carbon dioxide (CO_2) emissions as well as testing for evidence of the environmental Kuznets curve in 16 selected developing countries using data from 1990 to 2020 while employing the PMG and MG estimating techniques. Correlation analysis was performed. The presence of unit roots was checked using the IPS and LLC tests while the Kao tests was employed to test the cointegration among variables. Results from the environmental impact assessment revealed that while economic development promotes environmental degradation, the quadratic form of economic development abates environmental degradation. This result is a confirmation of the presence of the environmental Kuznets curve hypothesis in developing countries. It implies that at the initial stages of economic development, environmental degradation increases, however, beyond a certain threshold of economic development, environmental degradation declines.

Our findings further revealed that whereas renewable energy abates environmental degradation, non-renewable energy promotes environmental degradation in developing countries. Regarding the economic impact assessment, the findings of the study revealed that environmental degradation decreases economic development in developing countries. Interestingly, there was no evidence of the environmental Kuznets curve hypothesis when the effect of the quadratic form of environmental degradation on economic development was examined. This notwithstanding, both renewable and non-renewable energy was found to promote economic growth in developing countries.

Based on the empirical evidence presented in the study, the following policy recommendations are made. First, the evidence of the environmental Kuznets curve shows that policy makers should consider reducing environmental degradation in both the short and long run by employing critical and properly coordinated economic policies. Second, given the positive effect of renewable energy on the reduction in environmental degradation and promoting economic development, developing countries should consider implementing policies that discourage the use of non-renewable energy in favour of renewable energy.

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