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HOW DOES THE PATTERN OF ECONOMIC GROWTH IMPACT THE ENVIRONMENT? EMPIRICAL INSIGHTS FROM DEVELOPING COUNTRIES

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ABSTRACT

Countries around the world exhibit different patterns of economic growth, which can be broadly classified into resource-based economies and knowledge-based economies. The environmental impact of growth in these two types of economies varies significantly. It is commonly believed that resource-based economies tend to have higher emissions of CO_2, NO_2, and CH_4, leading to environmental degradation. On the other hand, knowledge-based economies, which focus on human capital and innovation, typically have lower emissions. This study investigates the impact of economic growth patterns on the environment in 61 developing countries from 1986 to 2022. The empirical analysis carried out through GMM estimation technique to address endogeneity issues generally prevailing in panel data set. Moreover, as the number of sectional units (N= 61) exceeds the time dimension (T=35), hence System GMM is used instead of difference GMM. The study findings indicate that countries experiencing knowledge-based economic growth tend to be more environmentally stable than those with resource-based economic growth. The study suggests that investing in technological innovation, human capital development, and renewable energy can help reduce emissions.

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INTRODUCTION

In order to attain Goal 12 of the Sustainable Development Goals (SDGs), nations across the globe are prioritizing issues that lead to environmental degradation because of economic growth (EG hereafter). A lot of the developing nations that have experienced high EG growth in recent decades are currently dealing with a huge environmental crisis, and this raises concerns about whether it EG is sustainable. EG plays a vital role in addressing the needs of individuals, as well as elevating living standards. Nevertheless, the question remains about how long-term such improvements are sustainable without the environment. In line with the conservation hypothesis, new empirical results by Rahman and Velayutham (2020), Chen and Fang (2018), and Nyasha et al. (2018), among others, state that EG may lead to additive environmental emissions.

The different patterns of EG are different in different countries of the world, which are divided into two broad categories such as resource-based economies and knowledge-based economies. These two kinds of economies may have different impacts on the environment. Mostly, it is noted that those economies that largely depend on conventional aspects have increased CO_2, NO_2, and CH_4 emissions, which cause a degradation of the environment. Conversely, the quality of environmental conditions improves in economies that place a higher priority on human capital and knowledge-based development (Hao et al., 2021; Aziz et al., 2024). Endogenous growth theory, including that of Romer (1986) and Lucas (1988) has placed significant emphasis on the fact that Total TFP is paramount to EG. EG is also technologically driven, and to stay competitive, every country must embrace the use of advanced technology to curb carbon emissions. This highlights the need to seek competitive strategies that would ensure sustainable development and keep afloat in the global economy. According to the endogenous growth theories, sustainable growth attainable with a healthy environment in the long run can be obtained in case growth performance is predominantly established on the basis of TFP.

TFP incorporates output productivity, the level of human capital (HC hereafter), entrepreneurial climate, competitiveness, technological development and innovation capabilities, and corporate efficiency. The innovation of technologies makes the efficiency of production functions more productive, coordinates the use of energy resources, and simplifies the shift to sustainable energies, reducing the emission of carbon dioxide (Churchill et al.2018). It is possible to decrease the use of fossil fuels in the manufacturing process by developing human capital. According to the analysis carried out by Yang et al. (2019) on the close connection between human capital and energy consumption, human capital helps decrease the usage of energy during the manufacturing process. HC has been believed to need to heighten energy competency to reduce the emission of the CO_2 gas (Kwon, 2009).

Besides, environmental consciousness is caused by a higher quality of HC that minimizes carbon emissions and environmental degradation. The increase of CO_2 emissions is posing a threat to the environment and the health of people. Lots of micro-level channels recommend that a negative correlation exists between the HC and carbon emission. It is known that a highly educated workforce promotes innovation in terms of research and development ($R\&D$) and energy-saving internal within the industrial sector (Ireland and Clausen, 2019). A manufacturing company that has a great number of skilled laborers has very slight probabilities of breaking the ecological rules of the environment (Blackman and Kildegaard, 2010). The question that has been raised by many environmentalists and economists is: "Is economic growth always bad for the environment?" This subject has elicited controversy because it is dynamic and broad-based based and as a result, there have been many studies that have been conducted to examine the effects of EG on environmental degradation. The impacts of EG on environmental degradation have been widely discussed in the literature, yet the particular influence of the growth pattern in developing countries has not been properly studied. The literature gap in the correlation between the pattern of EG and environmental degradation in developing countries exists. This paper investigates the relationship between EG and environmental degradation, which is comparative between resource-based and knowledge-based economies. The hypothesis being tested is that physical capital capitalized countries having EG will have a higher chance of environmental degradation, whereas those EG with knowledge (TFP) will have lesser effects on the environment. It was analyzed in 61 developing countries between 1986 and 2022. The study results will be of great importance to policymakers and scientists in their endeavors to establish the relationship that exists between EG patterns and environmental quality.

The research also provides a baseline for future research and contributes to the existing body of literature on the relationship between EG patterns and the environment. By focusing on the measures to face the issue of environmental degradation, this work can raise awareness and take measures to improve the environment in developing economies. The implications of the findings can be of great importance to policymakers to reduce the $CO2$ emission and promote sustainable EG.

METHODOLOGY

This section presents the research methodology and data used in the study. This section explains the empirical models used in the analysis. It also illustrates the definition and construction of the variables under consideration. It discusses the data and its sources and describes the sample and the criteria for sample selection. Finally, this section explains the estimation technique employed in the study.

Empirical Models

To meet the objective of the study, the following empirical model has been formulated. The empirical model is mainly based on Li and Ullah (2022), and the model has taken the following form:

$$ED_{it} = \beta_0 + \beta_1 ED_{it-1} + \beta_2 PEG_{it} + \beta_3 X_{it} + \varepsilon_{it} \quad (1)$$

Carbon dioxide emissions per capita in metric tons are used as a proxy for environmental degradation (ED_{it}) is our dependent variable. Pattern of EG (PEG_{it}) is the variable of interest. X_{it} is the vector of control variables, which consists of GDP per capita ($GDPC_{it}$), Population(POP_{it}), trade openness(TOP_{it}), total energy use(TEU_{it}), renewable energy use(REU_{it}), non-renewable energy use($NREU_{it}$), human capital(HC_{it}) and Physical capital(PhC_{it}). Where β_0 to the constant term, βs refer to slope parameters, $\varepsilon_{it}$is an error term that refers to the period.

Considering the nature of the variable of interest and energy consumption, our primary empirical model (Equation 1) is split into six separate empirical models, formulated as follows.

$$ED_{it} = \beta_0 + \beta_1 ED_{it-1} + ln\beta_2 PEG1_{it} + ln\beta_3 TEU_{it} + ln\beta_4 HC_{it} + ln\beta_5 Phc_{it} + ln\beta_6 GDPc_{it} + ln\beta_7 TOP_{it} + ln\beta_8 UPOP_{it} + \varepsilon_{it} \quad (2)$$

$$ED_{it} = \beta_0 + \beta_1 ED_{it-1} + ln\beta_2 PEG1_{it} + ln\beta_3 REU_{it_{it}} + ln\beta_4 HC_{it} + ln\beta_5 Phc_{it} + ln\beta_6 GDPc_{it} + ln\beta_7 TOP_{it} + ln\beta_8 UPOP_{it} + \varepsilon_{it} \quad (3)$$

$$ED_{it} = \beta_0 + \beta_1 ED_{it-1} + ln\beta_2 PEG1_{it} + ln\beta_3 NREU_{it} + ln\beta_4 HC_{it} + ln\beta_5 Phc_{it} + ln\beta_6 GDPc_{it} + ln\beta_7 TOP_{it} + ln\beta_8 UPOP_{it} + \varepsilon_{it} \quad (4)$$

$$ED_{it} = \beta_0 + \beta_1 ED_{it-1} + ln\beta_2 PEG2_{it} + ln\beta_3 TEU_{it} + ln\beta_4 HC_{it} + ln\beta_5 Phc_{it} + ln\beta_6 GDPc_{it} + ln\beta_7 TOP_{it} + ln\beta_8 UPOP_{it} + \varepsilon_{it} \quad (5)$$

$$ED_{it} = \beta_0 + \beta_1 ED_{it-1} + ln\beta_2 PEG2_{it} + ln\beta_3 REU_{it_{it}} + ln\beta_4 HC_{it} + ln\beta_5 Phc_{it} + ln\beta_6 GDPc_{it} + ln\beta_7 TOP_{it} + ln\beta_8 UPOP_{it} + \varepsilon_{it} \quad (6)$$

$$ED_{it} = \beta_0 + \beta_1 ED_{it-1} + ln\beta_2 PEG2_{it} + ln\beta_3 NREU_{it} + ln\beta_4 HC_{it} + ln\beta_5 Phc_{it} + ln\beta_6 GDPc_{it} + ln\beta_7 TOP_{it} + ln\beta_8 UPOP_{it} + \varepsilon_{it} \quad (7)$$

To better understand the impact of EG patterns on environmental degradation, we create dummy variables (0 and 1) to represent knowledge- and resource-based economies. We assign 0 to knowledge-based economies. Equations (2), (3), and (4) measure the impact of EG patterns on environmental degradation (ED_{it}), which is the dependent variable. Equations 2, 3, and 4 also demonstrate sensitivity analysis based on energy. It is often known that energy is a key factor in economic development and growth. It is an essential input in creating aggregate output, together with human and physical capital. Energy is an essential component of EG and a necessary infrastructure investment for the advancement of society (Azam, 2019). According to Alaali *et al.* (2015), energy should be viewed similarly to other production elements in neoclassical economics, such as capital and labor, since it is commonly acknowledged as being essential to economic progress. The study uses aggregate energy in equation 2, further broken down into renewable and non-renewable energy in equations 3 and 4. The amount of energy consumed by renewable sources reduces emissions significantly and is positively connected with living conditions in many countries.

Renewable energy consumption is considered a sustainable solution for reducing greenhouse gas emissions like $CO2$ and $SO2$, unlike other forms of energy consumption that harm the environment. Equations (5), (6), and (7) show how the pattern of EG affects environmental degradation, specifically $CO2$ emissions. The pattern of EG is determined by physical capital, which reflects the growth of the resource base. This study hypothesized that technology use would reduce emissions by increasing production efficiency. Human capital development (HDI) was expected to lower emissions, while increasing GDP was likely to raise $CO2$ emissions due to higher energy demand.

Conversely, greater use of renewable energy was expected to decrease $CO2$ emissions. Factors such as increased non-renewable energy consumption, population growth, and trade openness were expected to lead to higher emissions. The impact of gross capital formation on emissions could be positive. The system GMM model was employed to analyze the relationships among these variables. In a standard regression model, the relationship between an explanatory variable (x) and the dependent variable (y) is examined.

Definition and Construction of Variables

Dependent Variable

$CO2$ per capita in metric tons is used as a proxy for environmental degradation (ED_{it}), which is our dependent variable. $CO2$ emissions result from the burning of fossil fuels and contribute to the rising levels of carbon dioxide in the atmosphere, leading to global environmental changes. This is why $CO2$ is commonly used as an indicator of environmental degradation in studies. $CO2$ emissions were calculated as the logarithm of per capita

$CO2$ emissions in metric tons, like the approach used in the studies by Shahbaz and Sinha (2019).

Variable of Interest

The pattern of EG (PEG_{it}) defined as the relative contribution of factors of production, is a key variable of interest. Countries exhibit varying patterns of EG, with some being human capital dominant and others physical capital dominant. Countries whose growth is primarily driven by traditional factors like physical capital and the world average of TFP in a particular year serve as a threshold level. Countries above this threshold are considered knowledge-based, while those below are considered resource-based. A labor-based economy is known as a resource-based economy, a concept coined by Jacque Fresco, the creator of The Venus Project. On the other hand, economies that derive their growth mainly from knowledge (TFP) are classified as knowledge-based economies (Park et al., 2005).

Control Variables

Human capital ($\mathrm{HC_{it}}$) is defined as the kind of knowledge, skills, and health that people acquire and build throughout their lives so that they can achieve their full potential as productive society members. It is measured through the Human Capital Index in the Penn World Table. Physical Capital (PhC_{it}): Physical capital is measured through Gross Fixed Capital Formation as percentage of GDP. Renewable Energy Usage (REU_{it}): Renewable energy usage is proxied with share of energy from renewable sources per unit of energy consumption in kilograms of oil equivalent per capita. Non-Renewable Energy Usage (NREU_{it}) is measured with share of energy from non-renewable sources per unit of energy consumption in kilogram of oil equivalent per capita. It was anticipated that the addition to NRE usage would augment the discharge of $CO2$. Energy consumption was identified as a significant source of carbon emission in the process of economic development (Ang, 2007; Jahanger, 2022). GDP per capita is used as proxy of economic growth. It was anticipated that in the case of developing economies, there is a positive relationship between GDP and the discharge of CO2. The data is taken from WDI. Trade Openness (TOP_{it}) is measured as the ratio of trade to GDP, while Urban Population ($U\mathrm{POP}_{it}$) is captured with urban population as a percentage of the total population. The more the population of a nation, the more the strain will be put on the natural resources. On the demand side of the economy, the economic activities in the country will increase, and the economic activities will result in more production, which will also cause environmental pollution due to the degradation of the environment. Li and Ullah (2022) use the same variable in their study.

Data and Data Sources

The study utilized data from 1986 to 2022 and focused on 61 developing countries with available data. The variables examined include environmental degradation (CO2 emissions), TFP, GDP per capita, physical capital, HC, energy consumption, RENU, NREU, population, and trade openness. CO2 emissions were used as the dependent variable to measure environmental degradation, while the pattern of EG was the variable of interest. EG, physical capital, HC, energy consumption, renewable energy consumption, non-renewable energy consumption, population, and trade openness are control variables as suggested in the literature on the subject. The variables used in the study were extracted from the World Development Indicators and the Penn World Table 10.0 (2021). The sample countries are grouped into knowledge-based economies and resource-based economies. The study calculates the TFP of all economies based on human and physical capital by defining a threshold level. Countries with a score above average (threshold level) are considered knowledge-based economies, while those below the average are classified as resource-based economies.

Sample and Sample Selection Criteria

We analyzed yearly data from 1986 to 2022 for 61 developing countries, selected based on data availability. We established a TFP threshold to classify economies as knowledge-based or resource-based. Our hypothesis suggests that knowledge–based economies experience growth driven by human capital and lower carbon dioxide ($CO2$) emissions, while resource-based economies rely on physical capital growth and have higher $CO2$ emissions. Our sample consists of 61 developing countries from different regions of the world. The following are the reasons that limit our analysis to 61 developing countries. Firstly, developing countries are currently at a higher risk due to carbon emissions. Secondly, developing countries are major contributors to climate change in the 20th century.[1]

Estimation Technique

We utilized the two-step system GMM method to obtain reliable results. System GMM has emerged as an effective approach for addressing endogeneity issues in panel data models, considering problems such as simultaneity and reverse causality (Schultz et al., 2010). Our study also employs the GMM approach (Arellano and Bond, 1991) to address endogeneity concerns and enhance the robustness of our estimates. This method automatically selects appropriate instruments from the available variables in the system (Roodman, 2011). The system GMM equation confirmed all instruments' validity and the absence of AR (1) and AR (2) serial correlation in the error terms.

Empirical Findings and Interpretation

The empirical findings were obtained using the System GMM technique due to our dataset's smaller country dimension ($N = 61$) and larger time dimension ($T = 35$). Endogeneity needs to be addressed, and GMM is used to provide consistent and unbiased estimates. Tables 1 and 2 present the complete results of the empirical data. Table 1 shows the outcomes of knowledge-based EG, while Table 2 displays the results for resource-based.

Statistical Analysis

Table 1 illustrates the descriptive statistics of the variables under observation. The descriptive statistics for the variables used in this study for developing nations are explained in Table 1. The table adds mean, standard deviation, minimum, and maximum values for each variable. The standard deviation is the positive square root of the variance, and the mean represents the average value of the sample. The statistical distribution of the variables indicates that the sample countries have an average CO2 percentage of 3.57% with a SD of 4.69%. The mean CO2 value is closer to the minimum (0.047) than the maximum (31.27). Physical capital has an average of 21.60% with a standard deviation of 7.02%. The overall energy use averages 1506.45% with a standard deviation of 1932.37%. The standard deviation for renewable energy is 28.58% with a mean of 36.35%. Nonrenewable energy has a standard deviation of 28.25% and a mean of 67.20%.

[1] See Appendix 1A for the list of the sample countries.

Table 1. Descriptive statistics of variables under consideration.

Variable	No of Obs.	Mean	Std. Dev.	Min	Max
Carbon Dioxide Emission	1,859	3.5690	4.692	0.0473	31.2726
Physical Capital	2,010	21.555	7.099	0.0000	59.607
Total Energy Use	1,656	1506.453	1932.375	9.5790	11757.03
Renewable Energy Use	1,849	35.411	28.794	0.0090	94.988
Non-Renewable Energy Use	1,617	64.436	28.952	3.780	100
GDP Per Capita	1,910	11436.77	10672.1	430.413	75551.11
Urban Population	2,170	7.04e+07	2.12e+08	258370	1.41e+09
Trade Openness	2,061	71.1140	36.429	0.0209	220.4068

The population's mean is 7.04%, with a standard deviation of 2.12%. The GDP per capita average is 11436.77%, with a standard deviation of 10672.1%. Trade openness has an average of 71.11% with a standard deviation of 36.42%. The results show varying levels of variance among the variables.

Results of the GMM Estimates

This study examines how the pattern of *EG* affects environmental degradation. To differentiate between knowledge-based and resource-based economies, a dummy variable is used. Economies with knowledge-based growth, above a certain threshold, are assigned a value of 0, while those with resource-based growth below the threshold are assigned a value of 1. The threshold level for knowledge-based economies is determined by the average world *TFP*. A value above the average is considered a knowledge-based economy (valued 1), while a value below is considered otherwise (valued 0). The null hypothesis of the Sargan test is not rejected, confirming the validity of the instruments. Additionally, the first-order serial correlation AR (1) is significant at the 5% level, while the second-order serial correlation AR (2) is insignificant. This suggests the need for a dynamic model and validates the GMM estimation technique.

The estimated results of three knowledge-based analysis models, model 1, model 2, and model 3, are presented in Table 2. The analysis employs TFP as an indicator of a trend in EG (PEG1) and sums up energy consumption in model 1, and decomposes it into non-renewable energy and renewable energy in models 2 and 3, respectively. The findings show that the lagged dependent variable (EDit-1)) has a positive and significant correlation with the current CO2 emissions, indicating that past year emissions have a significant effect on current emissions. This can be explained by the fact that it is only possible when the biocapacity is bigger than the ecological footprint as it takes time before the earth can regenerate and upgrade. The estimated values of the first empirical model that investigates the effect of the pattern of EG (PEG) and control variables on CO2 emissions are presented in Column 2 of Table 2.

Table 2. Estimated results (Dependent variable is environmental degradation).

Variables	Model 1	Model 2	Model 3
ED_{it-1}	0.201***	0.650***	0.512***
	(0.000)	(0.000)	(0.000)
$PEG1_{it}$	-0.009**	-0.025***	-0.007***
	(0.016)	(0.000)	(0.053)
HC_{it}	-1.305***	-0.135**	-0.152***
	(0.000)	(0.015)	(0.000)
PhC_{it}	0.00083**	0.258***	0.006***
	(0.015)	(0.000)	(0.000)
$GDPC_{it}$	0.0002***	0.0164***	0.0001***
	(0.000)	(0.000)	(0.000)
TOP_{it}	0.0013***	0.204***	0.090***
	(0.000)	(0.000)	(0.000)
$UPOP_{it}$	0.631***	-0.928***	0.274***
	(0.000)	(0.000)	(0.001)
TEU_{it}	0.0015***	-------	-------
	(0.000)		
REU_{it}	--------	-0.021***	--------
		(0.000)	
$NREU_{it}$	--------	---------	0.497***
			(0.000)
$CONST_{it}$	-1.676***	-2.167***	-2.724***
	(0.000)	(0.000)	(0.000)
Obs.	1,200	1,302	1,201
No of Inst.	53	35	54
AR(1)	-2.2065	-2.2642	-1.9562
P. Value	(0.0273)	(0.0236)	(0.0504)
AR(2)	-0.8714	0.2014	0.6988
P. Value	(0.3835)	(0.8403)	(0.4847)
Sargan	45.8210	49.5578	51.3903
P. Value	(0.3965)	(0.5705)	(0.2708)

The variable of interest PEG is a statistically significant negative. The findings suggest that an increase in the contribution of total factor productivity to the growth process would lead to a reduction in the $CO2$ emissions. The approximate coefficient indicates a 0.009 metric ton reduction in CO 2 gas emissions per 1 percent rise in TFP. The result correlates with that of Khan et al. (2020), who showed that there was a negative correlation between TFP and CO2 emission. Hypothetically, TFP must be damaging to emissions since technological development, innovations, efficiency increases, and economies of scale will decrease the resources needed to create goods and services. Such improvements help to implement the use of effective home appliances, methods of production, machinery, and equipment, which result in minimized pollution and increased use of resources in a more rational manner. HC is a control variable with a negative coefficient that is statistically significant. According to the results, one percent of human capital will result in the reduction of $CO2$ emissions by 1.3 metric tons. This implies that the more the human capital is utilized in the growth process, the better the quality of the environment becomes. This result is consistent with other researchers who also concluded that there is a negative correlation between CO2 emissions and HC (Esquivias et al., 2022). By contrast to HC, the physical capital (PhC) is positively related to the model and statistically significant. The findings suggest that the more the growth rate of the countries is reliant on physical capital, the higher the emissions of $CO2$ are produced. The estimated coefficient indicates that a one percent rise in physical capital will cause a 0.00083 metric ton rise in CO2 emission levels. There is a statistically significant positive result of $GDPC$ variable. The coefficient of estimation shows that a one percent change in increase in the GDPC results in a 0.0002 metric ton change in the CO2 emissions. This finding is in line with the theory of the Environmental Kuznets Curve (EKC), which posits that environmental degradation grows as economies are developing at an early stage. Other researchers, such as Usman et al. (2022) and Sadiq et al. (2022), have also reported the same findings, revealing that the environmental degradation is expected to increase with the variable EG. The trade openness (TOP) indicates that there is a positive and significant relationship between the environmental degradation and CO2 emissions in countries of the sample. It is possible that this outcome can be attributed to the so-called Pollution Heaven Hypothesis, which says that in developing nations, environmental regulation turns weaker because of the openness to trade, which results in the spread of pollution-inducing technologies. There is a lot of literature that has shown a positive relationship between trade and carbon emissions (Shahbaz et al., 2017).

Table 3. Estimated results (Dependent variable is environmental degradation).

Variables	Model 1	Model 2	Model 3
ED_{it-1}	0.275***	0.705***	0.567***
	(0.000)	(0.000)	(0.000)
$PEG2_{it}$	0.0064*	0.0484***	0.0198***
	(0.094)	(0.000)	(0.000)
HC_{it}	-0.211***	-0.199***	-0.346***
	(0.001)	(0.007)	(0.000)
PhC_{it}	0.080***	0.226***	0.011***
	(0.000)	(0.000)	(0.000)
$GDPC_{it}$	0.005***	0.0002***	0.0002***
	(0.000)	(0.000)	(0.000)
TOP_{it}	0.058***	0.001***	0.004***
	(0.000)	(0.000)	(0.000)
$UPOP_{it}$	-0.006	-0.005	0.0069***
	(0.139)	(0.320)	(0.001)
TEU_{it}	0.001***	-------	-------
	(0.000)		
REU_{it}	--------	-0.675***	--------
		(0.000)	
$NREU_{it}$	--------	---------	0.034***
			(0.000)
$CONST_{it}$	-1.495***	2.252***	-1.991***
	(0.000)	(0.000)	(0.000)
Obs.	1,019	1,584	1,220
No of Inst.	31	35	54
AR(1)	-2.0718	-1.1529	-1.9789
P. Value	(0.0383)	(0.2490)	(0.0478)
AR(2)	0.91143	0.8851	0.66923
P. Value	(0.3621)	(0.3761)	(0.5034)
Sargan	27.4861	32.58418	52.5783
P. Value	(0.2358)	(0.2111)	(0.2344)

The CO2 emission in the sample countries has a positive relationship with the urban population (UPOP). The findings demonstrate that one percent urban population growth causes a metric ton of $CO2$ emission to increase by 0.631. This is to be expected because rural inhabitants in the emerging economies are flocking to urban areas in search of increased employment opportunities, increased standards of living, and increased access to social amenities. The migration of people to the urban areas requires additional resources to support the increasing population, like better infrastructure, like roads, hospitals, sewage systems, and a clean water supply. This shift depends on the consumption of fossil fuels to a significant extent, and this fact leads to the decline of the environmental condition. The same findings can be found in Su et al. (2022), Tan et al. (2022). The effect of the variable (TEU), total energy used, is statistically significant and positive. The estimated outcomes show that an increase in the consumption of energy in the sample countries by one percent will cause a 0.0015 metric ton growth in the CO2 emissions. This implies that the use of energy consumption in the sample countries positively correlates with CO2 emission, which implies that the greater the use of different energy sources, the greater the CO2 emission. Table 1 in model 2 (Column 3) has had the TEU changed to renewable energy use (REU). In contrast with total energy use, renewable energy use is negatively correlated and found to be statistically significant. The calculated outcomes show that the lower the renewable energies that a country employs in the production process, the lower the emissions. This implies that the developing countries can go a long way in curbing the emissions of CO2 by using renewable sources of energy, which include geothermal, solar, hydropower, biomass waste, biofuels, and wood.

Theoretically, due to the fact that the contribution of renewable energy to the overall energy consumption is more substantial as compared to fossil fuel, which contributes the vast majority of $CO2$ emissions, the adverse effect of renewable energy on the emissions is fully realistic. These findings are similar to those of Esquivias et al. (2022). The pattern of EG (PEG1) is the variable of interest, and all the control variables demonstrate the same outcomes as model 1. In model 3 (Column 4) of Table 3, REU is substituted with NREU Unlike REU, NREU enters the model with a positive value and is significant. The findings indicate that the CO2 emission rises with the rise in the consumption of non-renewable sources of energy in the sample countries. This implies that the developing countries can make great efforts in lessening their emission of CO2 through reduced consumption of non-renewable sources of energy, including fossil fuels. The same results have been reported by Abbasi et al. (2020). The variable of interest, the pattern of EG ($\mathrm{PEG1_{it}}$), and all control variables exhibit consistent results as in models 1 and 2.

The study aims to investigate the impact of the pattern of EG on environmental degradation. The policy variable in focus is the pattern of $EG,$ which refers to the relative contribution of factors of production to EG. In this study, two measures are used to assess the pattern of EG. Firstly, based on Park et al. (2005) and Haq et al. (2022), economies primarily relying on knowledge (TFP) for growth are categorized as knowledge-based. The world average of TFP in a specific year is used as a threshold level, with countries above this threshold classified as knowledge-based and those below as resource-based. Like TFP, the world average physical capital in a specific year is used as a threshold level, with countries above this threshold classified as resource-based and those below as knowledge-based.

Column 2 of Table 3 displays the estimated values of our first empirical model, which examines the impact of the pattern of EG ($PEG2_{it}$) and control variables on CO2 emissions. The variable of interest ($PEG2_{it}$) has a statistically significant positive sign. The results indicate that $CO2$ emissions increase with the role of traditional factors (physical capital) in the growth process. Hypothetically, $CO2$ emissions increase with an increase in the use of physical capital. This is because when savings are generated from households, these savings are further invested by households. These investments can be accumulated as funds that are used to produce capital goods. When an economy has more capital, it will increase its production capacity; more output will be produced. This industrialization will bring efficiency in production by creating negative externalities on the environment by increasing $CO2$ emissions and landfills. The findings are consistent with research conducted by Ahmed et al. (2017), Khalid et al. (2021), and Afridi et al. (2019).

CONCLUSIONS

The study analysed the impact of the pattern of EG on environmental degradation. The pattern of EG is captured by a knowledge-based economy and a resource-based economy. The dataset spans from 1986 to 2022 and includes 61 developing countries from various regions around the globe. The study's findings consist of six models that assess the impacts of EG on environmental degradation. The empirical estimates from the GMM indicate a close link between environmental sustainability and the pattern of EG in the sampled countries. Countries experiencing knowledge-based EG tend to be more environmentally stable than those with resource-based EG. The study suggests that investing in technological innovation, human capital development, and renewable energy can help reduce emissions. On the other hand, factors like non-renewable energies, capital formation, total energy consumption, EG, population, and trade openness contribute to emissions. The study recommends integrating human capital, technology, and renewable energy investment with EG to mitigate environmental impact.

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Appendix 1A. List of sample countries.

Angola	Argentina	Armenia	Russian Federation
Bahrain	Barbados	Benin	Romania
Bolivia	Botswana	Brazil	Serbia
Bulgaria	Cameroon	Chile	Sri-Lanka
China	Colombia	Costa Rica	Tajikistan
Ecuador	Egypt, Arab Rep.	Eswatini	Togo
Fiji	Gabon	Guatemala	Turkey
Honduras	India	Indonesia	Uruguay
Iran	Iraq	Jamaica	Zimbabwe
Jordan	Kazakhstan	Kenya	Senegal
Kuwait	Lesotho	Malaysia	South Africa
Mauritius	Mexico	Moldova	Sudan
Mongolia	Mozambique	Namibia	Thailand
Niger	Nigeria	Pakistan	Tunisia
Peru	Philippines	Poland	Ukraine
			Zambia