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Investigating Energy Use, Environment Pollution, and Economic Growth in Developing Countries

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***Abstract* – Attaining continuous economic growth entails special consideration of energy sector and the environment. Compliance with this purpose may be more intricate in the uncertain milieu of developing countries. The present paper examines the nature of causality between energy consumption, environment pollution, and economic growth in 8 contiguous developing countries, considering GDP per capita, CO_2 emissions, energy use, labour force, total population, urban population, capital formation, financial development, and trade openness. The author applied spatial simultaneous equations for random effects panel data to investigate the spatial interactions of adjacent countries over the period from 1998 to 2011. The findings reveal that energy consumption, environment degradation, and economic growth of a country influence those of its neighbours. Additionally, the results document bidirectional causal relationship between economic growth and environment pollution, as well as between environment pollution and energy consumption. Thus, there is a bidirectional relationship between energy use and economic growth. Fossil fuels replacement with renewable energy and usage of tax instruments to reduce greenhouse gas are recommended.**

***Keywords* – Economic development; energy consumption; energy economics; environment degradation, spatial simultaneous equations.**

1. INTRODUCTION

Environment degradation has become a global challenge in recent decades that stimulates decision makers to act not only within their countries but also in the international realm. Greenhouse gas emissions is one of the serious threats in developed and developing countries. According to Intergovernmental Panel on Climate Change (IPCC), carbon dioxide (CO_2) emissions comprised 76 percent of greenhouse gas around the globe in 2014. Therefore, decreasing CO_2 emissions has a major role in protecting global environment and proceeding its sustainable development [1]. Numerous studies have been conducted to identify influential factors of CO_2 emissions and their relationship with other socio-economic variables such as economic growth and energy consumption [2]–[6].

Energy has a major part in a country's economic growth so that it is referred to as a driver in most activities of service and production sectors. Energy consumption, on the other hand, leads to environmental damages because of greenhouse gas and CO_2 generation. It may seem that there is a paradox or dichotomy between a high economic growth and preserving the environment for decision makers in developing countries. However, according to evidence from developed countries, not only there is no paradox regarding this matter but also the economic growth facilitates the improvement of the environment, if the road to that growth has been established

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correctly by adopting efficient policies. Generally, economic growth is a gradual process in which the production capacity of a nation is developed in the course of time, generating a higher level of income for the country. If the policy to attain economic growth is designed based on utilising advanced technology and the acquisition of new applied science, which are pivotal moving forces of economic growth, then environmentally sustainable growth is achieved at minimum cost to the economy.

Although the case is more complicated for policy-making in the uncertain climate of developing countries, this is viable by understanding the relationships between the level of economic activity and greenhouse gas emissions. Therefore, all countries must be aware of these relationships in order to experience economic growth along with environmental considerations. Hence, the present paper is being directed to study the interactions between energy use, economic growth, and environmental contamination regarding the uncertain atmosphere existed in developing countries.

In this paper, the author tries to find answers for these questions: (i) Is there any mutual relationship between economic growth, environment pollution, and CO_2 emissions specifically in the uncertain situation of developing countries? (ii) To what extent does a country affect these factors in its neighbours? Therefore, the methodology adopted is the application of spatial simultaneous equations instead of using traditional econometric methods that helps us investigate adjacency effects. The foundation of spatial econometrics was established for conducting an inter-country research in Europe in 70's [7]. This approach provides a good platform for analysing location dependencies. Thus, the aim of this context is to study the adjacency effects via spatial paradigm which examines all the possible facets that spatial interactions can influence the nexus between economic growth, environment pollution, and CO_2 emissions. Hence, the present paper contributes to the related literature (e.g. [8]–[14]) by applying spatial econometric method and considering developing countries where the uncertainty undermines rigorous implementation of the modifying policies.

The remainder of the paper is structured as follows. In section 2 a review of spatial econometrics and related works are presented. The research methodology is described in section 3. Empirical results of spatial simultaneous equations using random effects panel data and discussion are presented in section 4. Section 5 concludes the paper with suggestions for the future.

2. LITERATURE REVIEW

2.1. Environmental Kuznets Curve

Understanding how economic growth influences the environment has become increasingly debated. Numerous studies (e.g. [15]–[17]) have modelled the environmental quality and economic growth nexus via emissions–income relation. Most of these studies have been formulated by the so-called environmental Kuznets curve (EKC) theory [18]. EKC asserts that there is an inverted U-type relationship between environmental quality and income per capita. This theory implies that at the initial stage of economic growth the awareness of environmental problems is low and also the environmental technology is not accessible over this span; therefore, environmental damages along with income growth culminate. Then, by increase in environmental awareness, executing environmental regulations, using better technology, and spending higher environmental preservation expenditure the damage level decreases steadily. Hence, there is an inverted U-shape relationship between environmental degradation and income per capita. On the other hand, [19] and [20] propound a monotonic rising curve. References [21]–[23] propose N-shaped curve which implies that after passing a phase like EKC**,** more economic growth eventuates in more environment deterioration. However, in [24] no significant relationship between CO_2 emissions and economic growth is reported.

2.2. Energy consumption and economic growth

Nowadays, energy is an important resource of production along with labour and capital. Reference [25] demonstrates that energy is one of the production factors in their proposed production function which has a tenuous connection with labour.

$$Q = \mathrm{F}(H(K,E),L), \tag{1}$$

where

- Q gross domestic product (GDP);
- H production factor;
- L labour force;
- K capital;
- L energy.

Reference [25] found that combination of capital and energy generates the production factor. Then, it incorporates labour force in order to produce goods [26]. Also, according to the growth model introduced in [27], the production process requires a substantial energy resource so that energy is the only growth factor. Therefore, capital and labour force are mediators that need energy in order to be operative [26]. Production function including labour, capital, and energy can be formulated as shown in Eq. (2).

$$Q = \mathrm{f}\,(K,L,E) \tag{2}$$

It is assumed that there is a directional relationship between the production level and the function of these variables. In other words, an increment in using of these factors increases the production outcome, therefore:

$$\frac{\partial Q}{\partial K}>0, \frac{\partial Q}{\partial L}>0, \frac{\partial \mathrm{Q}}{\partial \mathrm{E}}>0. \tag{3}$$

Eq. (3) is known as the positive marginal productivity implying that there would be a positive variation on production based on the variation of capital, labour force, or energy. It shows a partial derivative of gross domestic product with respect to capital, labour force, and energy.

2.3. Related Studies

Causality between energy use, CO_2 emissions, and economic growth has been widely investigated but the results seem to be heterogeneous. Reference [28] studies the causality between energy consumption and economic growth in Pakistan using Hsiao's Granger causality test. Their findings indicate that economic growth causes energy consumption. Reference [29] investigates the causal relationship between electricity use and GDP in Turkey showing electricity use has a significant impact on income per capita. Authors also show that the supply of electricity is necessary to retain economic growth of the country. Reference [30] confirms the existence of a causal relationship between energy use and economic growth in Tunisia using vector error correction (VEC) model. Reference [31] studies relationships between CO_2 emissions, energy consumption, and real GDP in selected MENA countries over the period from 1981 to 2005 by implementing bootstrap panel unit root tests. Authors report that GDP of selected countries has a quadratic relationship with CO_2 emissions. Reference [32] examines CO_2 emissions and energy use relationship in Iran and finds that GDP is of a significant effect on energy consumption. Also, economic growth is of a significant impact on energy use. References [33] and [34] show that CO_2 emissions influences GDP and energy consumption. Further, several studies report that energy consumption can elevate GDP and CO_2 emissions [35]–[38]. Reference [39] examines the causality between energy use and GDP in 119 countries around the globe using Granger causality and finds bidirectional relationship in 18 countries and a unidirectional relationship in 40 countries. Reference [40] finds a unidirectional causality from GDP to CO_2 emissions and a unidirectional relationship running from GDP to energy use in Bahrain. Authors show that economic growth gives rise to energy consumption. Finally, findings in [41] support a unidirectional causality from GDP to energy consumption. The abovementioned works provided a good foundation for more focused studies on other aspects of the relationship between economic growth, energy consumption, and carbon dioxide emissions presented in [42]–[46].

Since there is a mutual relationship between energy consumption, economic growth, and environment pollution, the present paper employs systems of equations while the majority of the previous works used one-equation approach and ignored the systematic causalities between relationships. Moreover, the author uses spatial approach because the behaviours and policies of different countries affect those of others and ignoring this matter rejects the Gauss-Markov assumptions. Therefore, the traditional econometric methods seem ineffectual and it is necessary to employ the spatial approach. Thus, this study uses an econometric model for spatial panel simultaneous equations.

3. METHODOLOGY

In this study, spatial panel simultaneous equations approach is employed to investigate the mutual effects of CO_2 emissions as environment pollution variable, GDP as economic growth variable, and energy use. Initially we test the existence of unit root in our data and check the possibility of using panel data. Next, we describe why the author utilizes simultaneous equations instead of multivariate regressions. In order to apply the spatial paradigm, spatial autocorrelation must be confirmed. The author explains how the spatial autocorrelation is tested and finally presents the system of equations. Following, the components of the adopted approach are introduced.

3.1. Panel data

Panel data provides appropriate framework to develop estimation methods and theoretical findings. In this framework researchers are capable of using cross-sectional time series for studying a kind of problems which cannot be investigated through time-series or cross-section study. Therefore, panel data is a proper way for conflating cross-sectional data and time series [47]. When it comes to panel data, the first step is to check the stationarity of the series through a variety of unit root tests. This is an underlying principle in the econometric investigation because using non-stationary variables causes spurious results. Hence, the author applies Levin-Lin-Chu test (LLC) introduced in [48]. LLC is one of the most well-known tests for stationarity investigation in the literature. The null hypothesis of LLC implies that there is a unit root in the variables. Rejecting the null hypothesis shows that all variables are stationary. Furthermore, the F-Limer test should be carried out to find out which one of the panel data or pooled data is appropriate. In this test, the null hypothesis implies that the individual effects of the model variables are equal and if at least one variable's effect is not equal to those of other variables the null hypothesis is rejected so that the panel data can be used.

3.2. Simultaneous equations

System of simultaneous equations structurally differs from multivariate regressions in a way that it might not support the classical assumptions of multivariate regressions. For instance, a dependent variable of an equation appears as an explanatory variable in another equation of the system. Such explanatory variable may be correlated with the residual of the same equation and this leads to the rejection of the very classic assumption of $\mathrm{cov}(u_i, x_i) = 0$ Using ordinary least squares estimators in such circumstance leads to biased and inconsistent results. Reference [49] recommends simultaneous equations approach to reduce the bias and inconsistency in the results. Eq. (4) shows the panel data regression with endogenous variables.

$$Y_{it} = \theta Z_{it} + \beta X_{it} + \mu_i + \nu_{it}, \tag{4}$$

where

i = 1, 2, …, N;

t = 1, 2, ..., T;

Z_{it} vector of endogenous variables.

These variables have correlation with v_{it}, which denotes time-order error. X_{it} represents the vector of exogenous variables and μ_i, is defined as the lag error. Most of econometric techniques emphasize on excluding or including the lag component (μ_i) in order to achieve the best estimation. Therefore, if it is assumed that μ_i is uncorrelated with other variables, the Random Effects method can be employed. Reference [50] introduces a random effects method, named Generalized Two Stage Least Square (G2SLS), which is used in Two Stage Least Squares (2SLS) regression using Generalized Least Squares (GLS) for estimation process. G2SLS is a consistent and effective method for panel data that does not need Hausman test for assessing the consistency of random effects [51].

3.3. Spatial paradigm

The data from contiguous countries constituted the sample of this study. Therefore, due to geographical aspect of the sample, the traditional econometric methods may lead to fallacious results because of spatial dependence between the observations and spatial heterogeneity in the relationships which reject the Gauss-Markov assumptions for conventional econometric methods [52]. Gauss-Markov assumes that the explanatory variables are fixed in repeated samplings. Furthermore, the spatial heterogeneity rejects Gauss-Markov assumption for the existence of a linear relationship with a constant variance across the sample data observations.

However, three main spatial models are used in econometrics, namely Spatial Lag Model, Spatial Error Model, and Spatial Durbin Model. The dependent variable propagates spatial effects in the Spatial Lag Model while error is the spatial propagation path in the Spatial Error Model. In the Spatial Durbin Model, the spatial propagation is considered through both the dependent variable and the independent variables. The present paper uses Spatial Lag Model or, in other word, spatial autoregressive model (SAR) including spatial and dependent variables of conventional regression models which are defined as follows:

$$y = \rho W y + \beta x + \varepsilon \,, \tag{5}$$

$$\varepsilon = N(0, Q^2 I_n),$$

where

y	vector of dependent variable;
x	explanatory variables;
W	spatial weights matrix;
β	parameters vector;
ρ	autocorrelation coefficient;
ε	independent error.

3.3.1. Neighbouring matrix

Creating neighbouring matrix or spatial weights matrix is the first step in designing the spatial pattern. This matrix shows the contiguity position among countries and defines spatial relationships between all of countries selected for the present study. W represents a weight matrix as follows.

$$W = \begin{bmatrix} 0 & w_{12} & \cdots & w_{1N} \\ w_{21} & 0 & \cdots & w_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ w_{1N} & w_{2N} & \cdots & 0 \end{bmatrix}$$

W is a symmetric matrix that its main diagonal elements are zero. Other elements of matrix are 1 if two countries are neighbours, otherwise they equal to zero. It is necessary for the neighbouring matrix to be standardized and multiplied by a dependent variable vector to achieve a new variable which represents the average observation of contiguous regions known as spatial lag variable [53]. Standardization is used to create proportional weights in cases where features have an unequal number of neighbours. Matrix standardization is performed by dividing each neighbour weight by the sum of all neighbour weights. We need this matrix to test the spatial autocorrelation which is described in the following sub-section.

3.3.2. Autocorrelation tests

Spatial autocorrelation presents a systematic spatial variation in a set of fixed areas located within a region [54]. Existence of spatial autocorrelation in the data is a sign of the fact that further analysis can be useful to ascertain the reasons behind the observed spatial variation [55]. Therefore, the spatial autocorrelation must be checked initially to find out whether or not the spatial paradigm can be applied. To gauge the spatial autocorrelation coefficient, the author uses Moran's I, Geary's C, and Getis-Ord tests. Null hypotheses of these test reject the existence of spatial autocorrelation in data. Most empirical studies applied Moran's I test to examine spatial autocorrelation [56]. Reference [57] formulates Moran's I test for different places as follows:

$$I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} C_{ij}}{s^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}} = \frac{\sum_{i=1}^{n} w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{s^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}}, \tag{6}$$

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}, \tag{7}$$

where

x_i and x_j are the values of X in different places;

s^2 is the variance of sample;

w_{ij}, which is known as weight matrix, is the spatial relationship between countries and represents the contiguity position between i and j [56].

Geary's C test is fairly similar to Moran's I. While Moran's I emphasis is on the deviation from the average observations, Geary's C underlines the differences between both sides [58]. Getis-Ord test is formulated as follows:

$$G(d) = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(d) x_i x_j}{\sum_{i=1}^{n} \sum_{j=1}^{n} x_1 x_j}, \tag{8}$$

where

x_i and x_j are the values of X in different countries;

w_{ij} known as the weight matrix, is the spatial relationship between countries and represents the contiguity position between i and j;

d denotes neighbouring distance. Each point beyond d is equal to zero so that it is dropped from the sample [55].

3.4. Research models

Pertinent literature provides numerous studies investigating the nexus between energy consumption, economic growth, and environmental pollution. Drawing on the literature, the author tries to include the most important and controversial determinants in the model equations to obtain a holistic view over the relationships in the selected developing countries. Several studies report a variety of controlling variables for studying the relationship between energy consumption, economic growth, and environmental pollution. References [26], [59] propounded that energy can be substituted for capital and labour and studied the nature of causality between economic growth and energy by incorporating the labour and capital in models. These variables were employed in other studies because labour and capital are two underlying components of production, having an undeniable impact on economic growth [36], [60]–[62]. Moreover, a sound financial development causes growth in the industrial sector of each country which leads to an adverse effect on the environment by augmenting carbon emissions. On the other hand, financial development indicates a country’s ability to assign financial resources to use environment-friendly technology in order to produce less CO_2 emissions [63]–[67]. Therefore, adding financial development in the model and investigating its effect on energy consumption can be promising. Similarly, research reveals that the total population of a country can have both negative and positive effects on the level of energy consumption [1], [68], [69]. Therefore, the authors incorporate this variable in the model to examine its effect on energy use in the contiguous countries. Another noticeable factor that can be included in the model equations is urban population as the literature shows contradictory results about this factor. While urban population decreases emissions in low-income countries, it influences emissions positively in high-income countries [70]–[73]. Since the selected countries in this paper are subsumed under different income categories ranging from high income to low income; therefore, the authors also add this variable in the equations to gain a better understanding of the results. Finally, research shows that trade openness can be helpful for the environment quality specially in developing countries because it increases their income and stimulates them to purchase and use advanced technologies to reduce CO_2 emissions [74], [75]. However, trade openness may also hurt the environment in developing countries due to the movement of dirty industries from home countries to developing nations where the governments just consider regulations and laws about the environment as a formality [76]. Hence, this variable is also added to the model equations.

The spatial panel simultaneous equations of this study are specified as follows:

$$\begin{aligned}\ln(GDP_{it}) &= \alpha_0 + \alpha_1 \ln(CO_{2it}) + \alpha_2 \ln(E_{it}) + \\ &\alpha_3 \ln(L_{it}) + \alpha_4 \ln(K_{it}) + \rho w_{it} \ln(GDP_{it}) + \varepsilon_{it},\end{aligned} \tag{9}$$

$$\begin{aligned}&\ln(E_{it}) = \xi_0 + \xi_1 \ln(GDP_{it}) + \xi_2 \ln(CO_{2it}) + \\ &\xi_3 \ln(L_{it}) + \xi_4 \ln(K_{it}) + \xi_5 \ln(FD_{it}) + \xi_6 \ln(POP_{it}) \\ &+\rho w_{it} \ln(E_{it}) + \Pi_{it},\end{aligned} \tag{10}$$

$$\begin{aligned}&\ln(CO_{2it}) = \phi_0 + \phi_1 \ln(E_{it}) + \phi_2 \ln(GDP_{it}) \\ &+\phi_3 \ln(UR_{it}) + \phi_4 \ln(TO_{it}) + \rho w_{it} \ln(CO_{2it}) + \phi_{it},\end{aligned} \tag{11}$$

where

i and t represent the country and time, respectively;

$\ln(GDP_{it})$ is the logarithm of gross domestic production per capita in constant 2005 USD;

$\ln(CO_{2it})$ denotes the logarithm of Carbon dioxide emissions (tons per capita);

$\ln(E_{it})$ is the logarithm of energy use (kg of oil equivalent per capita);

$\ln(L_{it})$ and $\ln(K_{it})$ are the logarithms of labour force and capital formation, respectively. $\ln(FD_{it})$ represents the logarithm of financial development, which is domestic credit provided by financial sector;

$\ln(P0P_{it})$ denotes the total population logarithm;

$\ln(UR_{it})$ is the urban population as percent of total population;

$\ln(T0_{it})$ represents the trade openness which is the sum of merchandise exports and imports divided by the value of GDP;

$w\ln(GDP)$, $w\ln(E)$, and $w\ln(CO_2)$ are the Spatial lag variables. Variables are presented in natural logarithms to decrease heteroscedasticity.

8 contiguous developing countries constituted the sample of this study. Armenia, Bangladesh, India, Iran, Oman, Turkey, Pakistan, and United Arab Emirates have been investigated over the period from 1998 to 2011. Of note is that all the relevant data were collected from World Bank website.

4. Results and Discussion

Owing to the simultaneity existing in the adopted models, the author uses instrumental variables and two-stage least squares to estimate each model separately. The author uses labour force, capital formation, financial development, total population, urban population, and trade openness as instrumental variables in order to investigate the interactions between energy use, carbon dioxide emissions, and economic growth in 8 contiguous developing countries. In so doing, the author uses random effects panel data and employs a generalized spatial two-stage least squares method. First, the stationarity of variables is examined by implementing LLC test. The null hypothesis of LLC supports the presence of a unit root in data, and the alternative hypothesis confirms that data are stationary. Table 1 presents the test results for logarithmic values of the variables. A big t statistic ($|t| \geq 2$) with a small probability of accepting null hypothesis (p-value) means that the null hypothesis is rejected. Therefore, results discredit the null hypothesis of unit root existence in the variables and it is confirmed that all the variables are stationary. Then, the author executes F-Limer test to illuminate if we are allowed to utilise panel data. The null hypothesis of F-Limer test, which implies that the individual effect of the model's variables is equal, was rejected. Therefore, using panel data is confirmed.

TABLE 1. RESULTS OF UNIT ROOT TEST

Variable	Probability of accepting null hypothesis	*T*-statistic
ln (*GDP*)	0.0318	1.89
ln (*E*)	0.0017	2.94
ln (CO_2)	0.0183	2.1
ln (*POP*)	0.0013	3.11
ln (*UR*)	0.0001	26.73
ln (*FD*)	0.0089	2.33
ln (*TO*)	0.0003	3.86
ln (*L*)	0.049	2.62
ln (*K*)	0.0041	2.71

TABLE 2. DESCRIPTIVE STATISTICS OF THE VARIABLES

Country	**Statistics features**	**GDP per capita, USD per capita**	**CO_2 emissions, tons per capita**	**Energy use, kg of oil equivalent per capita**	**Labour force, % of total population**	**Total population, *1000**	**Urban population, % of total population**	**Capital formation, USD millions**	**Financial development, % of GDP**	**Trade openness, %**
Armenia	Average	1633.13	64.08	168.71	47.73	3010.3	64.08	1055.79	14.62	68.59
	Std. dev.	477.66	0.35	21.23	1.17	39.14	0.35	503.41	9.98	8.26
Bangladesh	Average	510/173	0.29	166.71	46.44	143 189.31	27.24	288.6	31.02	35.44
	Std. dev.	6305.09	0.05	21.22	1.27	7172.88	2.53	63.31	6.46	6.57
Iran	Average	3210.69	6.82	2430.7	32.88	70 525.75	67.77	3563.84	41.29	33.04
	Std. dev.	446.63	0.77	366.72	2	2992.59	2.35	591.4	10.27	7.95
India	Average	775.96	1.33	476.65	39.40	1 152 177.5	29.42	673.96	39.83	33.26
	Std. dev.	168.52	0.02	57.47	0.87	63 729.27	1.19	261.34	8.64	12.43
Oman	Average	13 201.5	13.91	5255.7	38.48	2574.2	73.03	16 332.5	37.48	71.09
	Std. dev.	646.7	3.58	1423.6	4.4	286.8	1.54	6167.7	4.7	4.7
Pakistan	Average	704.98	0.88	487.76	32.43	155 358.6	34.97	430.65	24.45	18.82
	Std. dev.	62.08	0.08	21.31	1.72	11 542.1	1.26	35.29	3.6	15.05
Turkey	Average	7014.11	3.67	1301.5	33.87	68 231.55	68.05	3927.7	27.64	31.95
	Std. dev.	882.06	0.43	141.93	1.1	3223.3	2.14	950.87	13.32	14.5
UAE	Average	36 412.0	25.75	9533.5	63.01	5383.07	82.39	12 550.8	51.14	81.77
	Std. dev.	8125.6	5.02	1698/5	3.78	2089.2	1.35	1728.1	17.87	17.78

Before models' estimations, the descriptive statistics of the variables is presented in Table 2. Accordingly, the UAE has the greatest amount of average energy use (36412.01) and average GDP per capita (55235.35). Armenia is the most pollutant country by the average value of 64.08 metric tons of carbon dioxide emissions per capita. Bangladesh has the least average of energy use (166.71), CO_2 emissions (0.28), and GDP per capita (510/173). The least dispersion of energy consumption, GDP per capita, and CO_2 emissions are for Bangladesh (21.22), Pakistan (62.08), and India (0.02), respectively. The UAE has the most dispersion in all abovementioned items.

In order to enter the spatial lag variable in the models, it is necessary to constitute the contiguity matrix. The author forms a 64×64 adjacency matrix as 8 contiguous countries have been selected in this context. Then, we implement Moran's I, Geary's C, and Getis-Ord tests of which the null hypothesis corroborates that the data is randomly distributed and there is no spatial autocorrelation. The results presented in Table 3 confirm the presence of spatial autocorrelation; hence, using spatial paradigm in studying the causality between economic growth, CO_2 emissions, and energy consumption is supported.

TABLE 3. THE RESULTS OF AUTOCORRELATIONS TESTS

Equation	Test	Value	Probability
9	Moran's I	6.78	0.0000
	Geary's C	–5.80	0.0000
	Getis-Ord G	–6.78	0.0000
10	Moran's I	4.86	0.0000
	Geary's C	–3.46	0.0007
	Getis-Ord G	–4.86	0.0000
11	Moran's I	6.72	0.0000
	Geary's C	–3.18	0.0014
	Getis-Ord G	–6.72	0.0000

TABLE 4. RESULTS OF SPATIAL AUTOREGRESSIVE MODEL ESTIMATION

Dependent variable: ln (GDP)		
Independent variable	**Coefficient**	***T*-value**
Y intercept	0.53^{*}	1.84
ln (CO_2)	-0.03^{***}	–6.32
ln (E)	0.41^{***}	6.11
ln (L)	–0.35	–7.98
ln (K)	0.47***	7.61
W * ln (GDP)	0.003*	2.19
(Buse) R^2	0.99	–
(Buse) R^2Adj.	0.99	–
Raw Moments R^2	0.99	–
Raw Moments R^2 Adj.	0.99	–

***, **, and * denote statistical significance at the 10 %, 5 %, and, 1 % levels, respectively

The estimation results by *Stata 14* software for economic growth are shown in Table 4. The model validity is assessed by *R* square value that indicates almost 99 % of the variance in economic growth was accounted for by the variables introduced in Eq. (9). The contiguous matrix coefficient, ρ in Eq. (5), is significant which confirms applying spatial paradigm. This corroborates that the selected countries' economic growth was influenced by that of the adjacent countries. The spatial lag coefficient is positive meaning that the contiguity of countries has a positive impact on their economic growth. According to the model coefficients, the effect of labour force on economic growth is negative. This means by 10 % increase in labour force, the economic growth decreases by 3.5 %. This negative impact originates in labour intensive technology rooted in the nature of developing countries' production sector. However, using excessive labours in most of industries is accompanied by a descending return in productivity. Therefore, job growth in these countries does not necessarily leads to production growth. Increment in capital formation gives rise to economic growth in selected countries. In other words, 10 % increase in capital formation augments economic growth by 4.7 %. Since investment in production sector is lesser than the desired amount in the selected countries; therefore, there is a big potential for further capital-intensive technology which will bring economic growth for these countries. The energy use coefficient is positive (0.41) and statistically significant (*t*-value = 6.11). This indicates that an increase in energy consumption by 10 % elevates economic growth by 4.1 %. Hence, it is patent that the energy resource is a pivotal factor in economic growth. This finding is in consonance with the results presented in [1], [77], [78]. Moreover, CO_2 emissions influences economic growth negatively which is in line with [1], [79]. According to the model coefficients, 10 % increase in CO_2 emissions reduces 0.3 % of economic growth. This can be justified by paying attention to the fact that the manufacturing sector in most of the selected developing countries is not as advanced and prominent as it is in developed nations. As CO_2 emissions reduces the environmental quality, it may cause a negative effect to economic growth by influencing human health which would decrease productivity and hurts production in the long term.

Table 5 shows the estimation results for energy consumption. The model validity is evaluated by *R* square value that indicates almost 99 % of the variance in energy consumption was accounted for by the variables used in Eq. (10). The positive contiguous matrix coefficient (Y intercept) and spatial variable indicate that that the energy use of a country impacts on the energy consumption of the neighbours. According to the results obtained, CO_2 coefficient is positive and statistically significant (*t*-value = 2.31). That is to say, 10 % increase in CO_2 emissions escalates energy consumption by 0.1 %. Economic growth influences energy consumption positively as 10 % augmentation in GDP adds 4.4 % to energy consumption. Capital has a significant and positive effect on energy use of the selected developing countries. This means that 10 % increase in capital enhances energy use by 3.6 %. This positive effect was documented previously in [80]. Labour force has a positive but insignificant (*t*-value is lower than |2|), effect on energy consumption which is in line with [34] for the U.S. and [80] for Barbados. Financial development has also an insignificant and positive impact on energy use. Financial development improves business situation in these countries followed by an accumulated demand for energy. References [64], [65], [70], [81] report the same effect in their studies. Population influences energy use negatively and significantly. 10 % increase in population leads to the reduction of energy consumption by 0.3 %. Having greater population growth rate than energy consumption growth rate in selected developing countries might be a reason for this effect. On the other hand, this relationship can be justified by the growing trend of applying modern technology and using renewable energy resources in these countries.

TABLE 5. RESULTS OF SPATIAL AUTOREGRESSIVE MODEL ESTIMATION

Dependent variable: ln (E)		
Independent variable	**Coefficient**	***T*-value**
Y intercept	2.61***	2.84
ln (CO_2)	0.01***	2.31
ln (*GDP*)	0.44***	3.11
ln (*L*)	0.05	1.38
ln (*K*)	0.36***	4.09
ln (*FD*)	0.006	0.42
ln (*POP*)	–0.03*	–2.86
W * ln (*E*)	0.12**	1.96
(Buse) R^2	0.99	–
(Buse) R^2Adj.	0.99	–
Raw Moments R^2	0.99	–
Raw Moments R^2 Adj.	0.99	–

***, **, and * denote statistical significance at the 10 %, 5 %, and, 1 % levels, respectively

The value of contiguous matrix coefficient presented in Table 6, confirms that the selected countries' CO_2 emissions is influenced by the emissions of the neighbouring countries. *R* square indicates that almost 99 % of the variance in CO_2 emissions was accounted for by the variables used in Eq. (11); therefore, the validity of the model is confirmed. According to the model coefficients, GDP per capita has a statistically significant (*t*-value = 2.25) and positive effect on CO_2 emissions in a way that 10 % growth in GDP increases CO_2 emissions by 0.2 %. This means economic growth brings about environmental deterioration. This relationship is in accordance with the results presented in [10], [82], and [83]. Energy consumption affects CO_2 emissions positively and significantly. The results show that 10 % escalation in energy use leads to an increase in CO_2 emissions by 3.7 %. This finding shows that an increment in energy consumption causes environment destruction as reported in [84], [85]. In line with [1], urban population has a positive, but insignificant, impact on CO_2 emissions in the selected developing countries while in [72] a negative relationship is reported. Moreover, trade openness has a significant and positive effect on CO_2 emissions which is in accordance with [1] and [86] but is in contrary to [87]. According to the results, 10 % increase in trade openness augments CO_2 emissions by 0.3 %. Trade openness can cause a move in dirty industries from host countries to these developing countries as environmental regulations of these countries may not be as strong as it is in the host countries. Furthermore, trade openness links nations to the international markets where there is a competition between countries. As a result, these countries start to deplete their natural resources more rapidly in order to gain bigger share of international trade. This depletion of natural resources augments emissions and hurts environment [88], [89].

TABLE 6. RESULTS OF SPATIAL AUTOREGRESSIVE MODEL ESTIMATION

Dependent variable: ln (CO_2)		
Independent variable	**Coefficient**	***T*-value**
Y intercept	0.09	0.24
ln (*E*)	0.37^{***}	2.82
ln (*GDP*)	0.02^{**}	2.25
ln (*TO*)	0.03^{*}	2.88
ln (*UR*)	0.06	0.36
W * ln (CO_2)	0.48^{***}	4.01
(Buse) R^2	0.99	–
(Buse) R^2Adj.	0.99	–
Raw Moments R^2	0.99	–
Raw Moments R^2 Adj.	0.99	–

***, **, and * denote statistical significance at the 10 %, 5 %, and, 1 % levels, respectively

Considering the effect of energy use on economic growth in the selected developing countries, paying attention to energy consumption is a fundamental factor in warranting rapid and continuous economic growth [90]. Therefore, it is not necessary to lessen the consumption of energy to achieve CO_2 reduction because it results in declining GDP. However, replacing non-renewable and fossil fuels with clean and green fuels secures continuity of economic growth and reduction of CO_2 emissions. Hence, investing in clean energy must be an inseparable part of the CO_2 emissions control process. For instance, these countries can use, according to their geographical features, wind or solar energy as a substitution for the fossil energy.

Considering the growing trend of CO_2 emissions in the selected countries, new environmental policies must be adopted to reduce the environment degradation. According to the proposed model in this paper, increasing GDP and energy consumption leads to boosting contamination by CO_2 emissions growth. Thus, reducing pollution via decreasing GDP causes investment abatement and unemployment. However, energy use can be subsided by improving the productivity in energy consumption.

According to the findings of the present study, the author can confirm: (1) a bidirectional causal relationship between energy use and economic growth which is in line with [1]; a bidirectional causal relationship between energy use and CO_2 emissions which is in consonance with the results presented in [91] while [1] reports a unidirectional relationship in which energy use affects CO_2 emissions; (3) a bidirectional causal relationship between economic growth and CO_2 emissions which is in accordance with [92].

5. CONCLUSION

The greenhouse gas generation and its negative consequences on human welfare stimulate many researchers all over the world. Numerous factors influence the amount of greenhouse gas generation. The present paper studies interactions among environment pollution, economic growth, and energy consumption using panel data for spatial simultaneous equations in developing countries. The results indicate that energy use, economic growth, and environment pollution of the selected developing countries are influenced by those of the contiguous countries. Moreover, the research findings reveal bidirectional causal relationships between economic growth and energy use, environment pollution and economic growth, and also energy consumption and environment pollution. In this paper, the author used economic growth as a variable which represents the welfare.

According to the findings, energy consumption is a key driver of persistent economic growth in the selected developing countries. Hence, it is not necessary for these countries to exert stringent policy for CO_2 emissions as it may decrease their GDP. However, these countries can invest in modern technologies to replace non-renewable and fossil fuels with clean and green fuels. In this way, they can accomplish their missions germane to both economic growth and CO_2 emissions reduction. Therefore, investing in research and development for clean energy is an inseparable part of controlling CO_2 emissions. For instance, geographical features of these countries allow the usage of solar energy as one of the alternative substitutions for fossil fuels.

Considering the increasing level of CO_2 emissions in these countries, designing new environmental policy to reduce environment degradation is important. Based on our findings, increase in GDP and energy consumption augment CO_2 emissions which hurt the environment quality. Although environmental degradation can be subsided by a decline in GDP, this policy causes a reduction in the investment opportunities and job market within the selected nations causing an increase in the unemployment among them. However, this aim can be achieved by means of raising efficiency of energy consumption in their industries to decrease emissions and improve environment quality. Furthermore, governments may provide a good platform for reaching a sustainable economic growth by imposing tax on emissions, although it needs essential infrastructure and regulations.

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