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Article

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Investigating Growth-Energy-Emissions Trilemma in South Asia

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ABSTRACT

This paper situates the 2030 United Nations Sustainable Development Goals (SDGs) 7, 8, and 13 to investigate the growth-energy-emissions trilemma. It uniquely contributes to the discourse by using carbon emissions per capita (emissions), GDP per capita (economic growth), energy use per capita (nonrenewable energy) and renewable energy from seven South Asian countries covering 1990 to 2019 to determine the effect of economic growth and energy use on emissions and if its interaction with either energy variant enhances or dims the effect of energy on emissions. Consistent findings from panel-corrected standard errors (PCSE), feasible generalized least squares (FGLS) and bootstrapping ordinary least squares (BOLS) reveal that: (1) Economic growth intensifies emissions, (2) renewable energy exhibit emissions-reducing properties; (3) nonrenewable energy intensifies emissions, (4) economic growth sustains the emissions-reducing impact of renewable energy; and (5) economic growth diminishes the harmful effect of nonrenewable energy. Given these, we submit that the interaction of economic growth enables the “good” effect of renewable energy. At the same time, it reduces the “bad” effect nonrenewable energy on carbon emissions. These outcomes engender a new line of argument that the extent of economic growth cuts carbon emissions level. Therefore, economic growth is an essential determinant of carbon emissions. Policy implications discussed.

Keywords: Carbon Emissions, Economic Growth, Nonrenewable Energy, Renewable Energy, South Asia
JEL Classifications: C52, O40, O55, Q40, Q50

1. INTRODUCTION

This study fills a lacuna in the literature by interrogating the growth-energy-emissions trilemma. It presents some empirical discoveries which provoke a new perspective and highlights findings on whether economic growth ameliorates the impact of energy (renewable and nonrenewable) consumption on carbon emissions. That is, does the interaction of economic growth with either energy variant accelerates or diminishes the level of carbon emissions? Conclusions reveal, among other things, that renewable energy attenuates carbon emissions while economic growth and nonrenewable energy intensify emissions, the interaction of economic growth strengthens the “good” effect of renewable energy. At the same time, it slows the “bad” effect of nonrenewable energy. The complementary role of economic growth demonstrates that it is an essential determinant of emissions. These are significant incursions to the growth-energy-emissions discourse which justify engaging in this study – especially, from a cross-regional perspective.

Importantly, the drive to maintain a sustainable environment necessitated the 2030 United Nations Sustainable Development Goal (SDG) 13 agenda, which is to *“take urgent action to combat climate change and its impacts.”* Therefore, to address climate change, it becomes imperative to understand its contributing factors: one of which is carbon dioxide (CO_2) emissions. This study positions on South Asia for three reasons: (1) Pollution, (2) economic growth, and (3) energy demand. From United Nations (2019), in contrast to Pakistan, the economic conditions in Bangladesh, Bhutan and India are mostly positive with positive GDP growth projections. Lastly, energy demand is higher in Asia and projected to double between 2018 and 2050, making it both the largest and fastest-growing region in the world for energy consumption (EIA, 2019). Besides, India is one of the world's fastest-growing economies during much of the past decade, and they remain primary contributors to future growth in world energy demand (IEA, 2019b; 2019a).

To address the lacuna in the growth-energy-emissions literature, this study attempts to answer two questions: (1) does economic growth, renewable and nonrenewable energy individually influence emissions? (2) Does the interaction of growth and energy (renewable and nonrenewable) exacerbate or weaken emissions? To answer these questions, an unbalanced panel data of per capita GDP (a proxy for economic growth), renewable energy per capita, nonrenewable energy use, and carbon emissions per capita from seven selected South Asian[1] countries (Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka) spanning 1990–2019 is used to investigate if energy and economic growth contribute to carbon emissions. Similar to Shahbaz et al. (2016), this paper further differs from previous studies on South Asian countries (see Sharma et al. (2014), Uddin and Wadud (2014), Pandey and Mishra (2016), Osmani (2018), Rahman et al. (2020)) by strictly engaging a trivariate model to analyze the relationship. The empirical investigation employs the Praise-Winsten panel-corrected standard errors (PCSE), feasible generalized least squares (FGLS) and bootstrapping ordinary least squares (OLS). The results, for the most part, align with previous studies. However, the novel contribution is that economic growth does not dampen the "good" impact of renewable energy on carbon emissions such that the emissions-reducing effect of renewable energy is sustained. At the same time, it reduces the harmful impact of nonrenewable energy.

The rest of the paper is structured as follows: Section 2 reviews the empirical literature; section 3 outlines the data and empirical model; section 4 discusses the results, and section 5 concludes with policy recommendations.

2. BRIEF LITERATURE REVIEW

Rising environmental degradation has gained the attention of policymakers across the world with climate change constituting one of the Sustainable Development Goals (SGD) as SDG13. The drive towards economic growth and development of most nations seems to be putting the planet at risk in severe ways. (Afridi et al., 2019) noted that the key contributor to environmental degradation is human activities. These human activities, however, geared towards enhancing the standard of living and economic growth enables urbanization and with urbanization, comes an increase in consumption and demand for energy (Adedoyin et al., 2020). Some studies like (Chikaraishi et al., 2015); and (Xu et al., 2018) concluded that energy usage encourages modernization and smart cities while other studies like (Zhang et al., 2015) opined that economic development increases energy consumption. (Li and Lin, 2015), on the other hand, reported that energy use and environmental degradation have a varying relationship at the initial stage of economic development proxied by urbanization.

1 Afghanistan is excluded due to lack of data on nonrenewable energy.

Arguments revolving around the carbon emission-growth relationship is currently ongoing with no consensus on the nature of their relationship. The results of Uddin and Wadud (2014) after employing vector autoregressive analysis (VAR) estimation technique on a panel data set of seven South Asian countries showed that growth-emission has a positive and significant relationship. Similarly, (Saidi and Hammami, 2015) pointed out that carbon emission increases with economic growth for 58 countries across four continents based on the generalized method of moments (GMM) analysis. The study by (Pandey and Mishra, 2016) on how economic growth is affected by carbon emission performed cointegration analysis on panel data of South Asian countries equally proved that economic growth increases carbon emission and not the other way round as observed for South Asian countries as well. (Hasnisah et al., 2019) established that carbon emissions and economic growth exhibited a long-run relationship from the dynamic and fully modified ordinary least squares techniques. Efforts to ensure that carbon emissions are reduced in the world led to the alternative sourcing of renewable energy. (Pimentel et al., 2002), established that renewable energy presents an alternative option for the United States of America to meet the future energy needs of her population by half approximately without compromising the national security of the country.

2.1. Carbon Emissions and Renewable Energy

Since environmental challenges are rising as a result of increasing carbon emissions from the conventional energy source, more attention is given to renewable energy. (Adams and Nsiah, 2019) noted that renewable energy resource availability makes it a preferred source of energy consumption as proposed by the United Nations in SDG 7 mainly as it emits less carbon compared to the traditional source of energy. (Hasnisah et al., 2019) while engaging carbon dioxide, per capita GDP, fossil fuels and renewable energy concluded that for 13 Asian countries, renewable energy had no significant impact on the quality of the environment. Contrarily, (Abolhosseini et al., 2014) on the study of 15 European Union countries revealed that renewable energy sources led to a decrease in carbon emissions. The disparity in outcomes could be as a result of the diverse regions having different levels of energy consumption. More so, the population density of Asian countries is higher than that of Europe, thereby affecting human activities in regards to energy consumption. Furthermore, (Nguyen and Kakinaka, 2019) examined the relationship between renewable energy, nonrenewable energy, carbon emissions, real oil prices and economic growth. The result revealed that in low-income countries, renewable energy consumption and carbon emissions exhibit a positive relationship.

Likewise, (Wahid et al., 2018) performed the Granger causality test in an attempt to determine the direction of causality between carbon emissions, renewable energy and economic growth for Malaysia and Indonesia. The outcomes showed that renewable energy causes economic growth and carbon emissions for Indonesia. In contrast, for Malaysia, renewable energy and economic growth have a unidirectional causal relation from renewable energy to economic growth. It was observed that the availability of a variety of renewable resources in Malaysia might be responsible for this result. (Pata, 2018) used urbanization, financial development, carbon emission per capita, income, hydropower consumption, total renewable energy per capita and alternative energy variable to explain the income-emission relationship in Turkey. Findings showed that the inverted U-shaped environmental Kuznets curve (EKC) hypothesis holds for Turkey, and total renewable energy has no effect on carbon emissions.

On the other hand, (Al-Mulali et al., 2016) examined the role of renewable energy on environmental pollution for seven regions namely East Asia, Western Europe, East Europe and Central Asia, The Americas, South Asia, Sub-Saharan Africa and the Middle East and North Africa. The findings of the study revealed that a long-run relationship exists among all the variables employed, which included carbon emissions, urbanization, trade openness, GDP, financial development and renewable energy consumption. Furthermore, the result indicates that renewable energy reduced carbon emission for all regions except Sub-Saharan Africa, where EKC cannot be confirmed and the variables are statistically not significant.

2.2. Carbon Emissions and Income Per Capita

According to (Pandey and Mishra, 2016), the core of the EKC is that carbon emissions is determined by income. However, this hypothesis is protested on the basis that carbon emissions mostly occurs at the production stage; hence, carbon emission is expected to determine growth (per capita income). In other words, (Pandey and Mishra, 2016) discovered that per capita income encouraged carbon emission, not the other way round. Similarly, (Osabuohien et al., 2014) after carrying out panel cointegration for 50 African countries ranging from the year 1995 to 2010, discovered that the existence of long-run equilibrium relationship among the variables used. Additionally, EKC inverted U shape was verified in the emissions-income relationship implying that per capita income tends to increase enough beyond the threshold to bring about a reduction of carbon emissions eventually.

Furthermore, the study by (Aye and Edoja, 2017), showed the existence of unidirectional causality from GDP per capita to carbon emission for 10 out of the 31 African countries used in the analysis. The ten countries consisted of a mixture of low income and middle-income countries. Using threshold analysis with the pegging of GDP per capita threshold at 0.93 per cent, countries below the threshold are classified as low-income. In contrast, those above are classified as high-income countries. The outcomes revealed that for low growth regime, GDP per capita had a positive effect on CO_2 emission and vice versa in high growth regime. The result of (Asumadu-Sarkodie and Owusu, 2017) contradicts how per capita income responds to carbon emission after employing the ARDL bounds test to examine the existence of a long-run relationship between GDP per capita and carbon emission for Rwanda. Findings showed that in the long-run, a percentage increase in GDP per capita led to a 1.45 per cent decrease in carbon emissions which confirms the existence of a long-run relationship among the variables. However, the Granger causality test did not establish any directional relationship between carbon emission and GDP per capita.

(Adu and Denkyirah, 2017) tested the environmental Kuznets curve hypothesis for West African countries in the same income category (lower middle-income) and how economic growth influenced ecological degradation in these countries by employing a panel data analysis from 1970 to 2013. The study analyzed the relationship among environmental degradation measured by carbon emissions, combustible renewable waste, economic growth measured by per capita income, and other determinants such as trade openness, population density, and official exchange rate using the fixed effect and random effect models. The results showed that GDP per capita had a positive impact on CO_2 emissions and was statistically significant at 1% and 5% significance levels. The study, therefore, concluded that while per capita income increased carbon emissions in the short-run, it did not decrease environmental degradation in the long run. Hence, the EKC hypothesis does not exist in West Africa in the long run, and pollution does not decrease as income increases.

However, empirical findings on single country analyses like that of Nigeria (Ejuvbekpokpo, 2014; Ali et al., 2016; Egbetokun et al., 2020) yielded conflicting results. While (Ejuvbekpokpo, 2014) employed the use of ordinary least squares (OLS) estimation technique to determine the impact of carbon emissions on economic growth and discovered that carbon emissions negatively impacted growth, (Ali et al., 2016) modelled carbon emissions as a function of the urban population, income, trade openness and energy consumption using the ARDL approach. It showed that urban population, although positive, has no significant impact on carbon emissions whereas, income measured by GDP and energy consumption are both statistically significant. (Egbetokun et al., 2020) on the other hand, measured environmental pollution with six distinct variables – carbon dioxide, nitrous oxide, suspended particular matter (SPM), total greenhouse (TGH) emissions, temperature and rainfall. These variables are modelled individually and showed that the EKC hypothesis was applicable in Nigeria but not for all pollution variables.

Another single country empirical literature from West Africa on how income per capita impacted on carbon emissions was carried out by (Twerefou et al., 2016) that attempted to verify the EKC hypothesis for Ghana. It was observed that the EKC hypothesis does not apply in Ghana, given that the long-run estimates indicated a negative yet significant relationship between carbon emissions and income per capita after a long-run relationship was detected. This suggested that as per capita income increases, carbon emissions increase. The result of this study corresponds with that of (Sarkodie and Strezov, 2018) that equally rejected the existence of EKC hypothesis for Ghana in the empirical study to establish EKC hypothesis for Ghana, China, Australia and the United States of America. (Ali et al., 2017) found EKC present in the long-run for Malaysia after carrying out a study using ARDL bounds testing technique to determine if a long-run relationship existed between real GDP per capita, trade openness, financial development, foreign direct investment (FDI) and carbon dioxide emissions. The study showed that per capita GDP and trade openness caused a significant increase in carbon emissions.

Similarly, the EKC hypothesis was discovered in some OECD countries after (Churchill et al., 2018) employed panel data cointegration techniques for 20 OECD countries from 1870 to 2014. The carbon emissions per capita, which represented environmental indicator, GDP per capita as well as its squared, financial development measured by broad money to GDP, trade and population were the variables considered in the study. Using the pooled mean group (PMG) estimator, the study noted that in the long-run, the effect of per capita income on environmental degradation gradually increased. The robustness of the study can be due to the coverage of over 145 years.

(Apergis, 2016) examined the validity of the EKC hypothesis by analyzing the income-emissions relationship for 15 OECD countries using a panel data time-varying fully modified OLS and quantile cointegration approach from 1960 to 2013. The quantile cointegration approach validated the EKC hypothesis for 12 of the countries studied. The results also showed that the link between income per capita and carbon emissions per capita for most of the countries is nonlinear. Also, (Afridi et al., 2019) examined income-emissions relationship for the South Asian countries from 1980 to 2016 while also testing the EKC hypothesis. Using the generalized least squares (GLS) verified that EKC exhibits an N-shaped relationship. For space, Table 1 details the summary of selected and additional literature on carbon emissions, renewable energy consumption and per capita income.

3. DATA, MODEL, AND EMPIRICAL APPROACH

3.1. Data and Sources

The study scope covers seven South Asian countries (Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka) from 1990 to 2019. Afghanistan is dropped due to a lack of data on

Table 1: Summary of literature review

Authors	Period	Methodology	Results
Abolhosseini et al. (2014)	1995–2010	Panel data estimation	Positive relationship between carbon emission and GDP per capita
Ejuvbekpokpo (2014)	1980–2010	Ordinary Least Squares	Carbon emission adversely affect economic growth
Osabuohien et al. (2014)	1995–2010	Panel cointegration estimation techniques	Existence of inverted-U EKC curve, Long-run equilibrium relationship among the variables
Uddin and Wadud (2014)	1972–2012	Vector Autoregressive Analysis	Long-run equilibrium relationship present. GDP → CO2
Al-Mulali et al. (2016)	1980–2010	Non-stationary panel cointegration technique, DOLS, VECM and Granger Causality	Long-run relationship among the variables in all the 7 regions, EKC hypothesis, cannot be confirmed in Africa. Renewable energy reduced carbon emission in all regions except Africa
Ali et al. (2016)	1971–2011	ARDL cointegration technique	Long-run equilibrium relationship among the variables, EC→CO2
Apergis (2016)	1960–2013	Panel data time-varying, fully modified OLS and quantile cointegration approach	Validated EKC hypothesis for 12 out of 15 countries. Per capita income and carbon emissions exhibited a nonlinear relationship
Pandey and Mishra (2016)	1972–2010	Panel Vector Error Correction Model and Panel Cointegration analysis	GDP per capita → CO2
Twerefou et al. (2016)	1970–2010	ARDL Bounds testing	Presence of long-run equilibrium relationship among the variables. Non-existence of EKC hypothesis in Ghana
Aye and Edoja (2017)	1971–2013	Dynamic threshold model and Panel Causality test	Estimated GDP threshold to be 0.93% GDP→ CO2
Adu and Denkyirah (2017)	1970–2013	Panel data fixed effect and random effect model	EKC does not exist in the long run in West African countries. Per capita income does not decrease environmental degradation in the long run
Ali et al. (2017)	1971–2012	ARDL cointegration technique	The presence of EKC in Malaysia, per capita income, significantly causes environmental pollution
Churchill et al. (2018)	1870–2014	Panel cointegration estimate techniques	EKC holds for 9 out of 20 countries OECD countries
Pata (2018)	1974–2014	ARDL Bounds testing, Gregory-Hansen and Hatemi-J cointegration tests.	Inverted U EKC hypothesis was validated for Turkey
Wahid et al. (2018)	1980–2011	Johansen Cointegration and Granger causality test	Long-run relationship among the variables. Indonesia RE → CO2, RE → GDP, Malaysia, EC→ CO2, RE →GDP, GDP → RE
Afridi et al. (2019)	1972–2010	GLS estimation technique, Granger Causality tests	Bi-directional causality between CO2 and income per capita. Long-run relationship between the variables
Hasnisah et al. (2019)	1980–2014	FMOLS and DOLS	FOSS → CO2, GDP → CO2, EKC hypothesis validated
Nguyen and Kakinaka (2019)	1990–2013	Panel data cointegration, FMOLS and DOLS	REC → CO (low-income countries), REC → GDP (high-income countries), NREC → GDP and Y (high and low income
Egbetokun et al. (2020)	1971–2010	EKC Model, ARDL cointegration and ECM	The presence of EKC for a selected measure of environmental pollution in Nigeria. Long-run equilibrium relationship among the variables

energy per capita. Carbon emissions (CO_2PC) is the dependent variables measured in metric tonnes per capita. The explanatory variables are share of renewable energy *(RENW)* in total final energy consumption measured as percentages of total energy consumption, gross domestic product per capita *(PC)* measured by gross domestic product divided by the population is the proxy for economic growth and total energy used *(ENU)* proxy by kilogram of oil equivalent per capita energy. Lastly, interaction terms of per capita income and renewable energy *(PC*RENW)* and per capita income and nonrenewable energy *(PC*ENU)* are included to address the study questions. All the variables are sourced from World Bank (2019) World Development Indicators. Table 2 details the relative association (correlation matrix) among the variables.

From Table 2, all the explanatory variables show significant associations at the 1% level with carbon emissions. While both per capita income and energy use are positively associated, renewable energy reveals a negative relationship. The statistical properties of the variables are displayed in Table 3. The sample average for CO_2PC is 0.79 and the standard deviation of 0.64 reveals that the countries hover around the sample average. That is, there are not many differences in the level of carbon emissions per country. The standard deviation of 1968.55 for PC indicates a wide dispersion from the sample average of US$1879.99. Also, the average value of RENW is 3.65, and the standard deviation of 1.27 shows the countries are within the sample mean. Lastly, ENU has a mean value of 375.69 and a standard deviation of 144.31 evidencing greater dispersion from the sample mean.

Comparatively, Maldives shows to have the highest statistics for carbon emissions (1.86), per capita income (US$6,604.67), and energy use (701.35) while Bhutan marginally edges Nepal to earn the highest renewable energy per average (4.52).

Table 2: Correlation matrix

Variables	$\ln CO_2PC$	lnPC	lnRENW	lnENU
$\ln CO_2PC$	1.000			
lnPC	0.779***	1.000		
lnRENW	−0.614***	−0.759***	1.000	
lnENU	0.619***	0.617***	−0.343***	1.000

Source: Authors' Computations. ***indicate statistical significance at the 1% level; CO_2PC=Carbon dioxide emissions per capita; PC=GDP per capita; RENW=Renewable energy; ENU=Energy consumption per capita.

3.2. Model Specification and Estimation Techniques

To address the first objective about the impact of economic growth, renewable and nonrenewable energy on carbon emissions, the relation specifies carbon emissions (CO_2PC) as a linear function of per capita income (*PC*), renewable (*RENW*) and nonrenewable energy (*ENU*) expressed thus:

$$\ln CO2PC_{it} = \psi_0 + \psi_1 \ln PC_{it} + \psi_2 \ln RENW_{it} + \psi_3 \ln ENU_{it} + d_{it} \quad (1)$$

Where the variables are as defined in Section 3.1; ψ_i are the parameters to be estimated; i=1….N represents the number of cross-sections, t is the period; d_{it} is the general error is the general error terms. On *a priori* expectations, economic growth and nonrenewable energy consumption have positive relationships with carbon emissions. In contrast, renewable energy exerts a declining relation to emissions as higher consumption of cleaner energy lowers the level of carbon emissions. (Nguyen and Kakinaka, 2019; Destek and Sinha, 2020; Nathaniel et al., 2020b).

Similarly, to address the second and third objectives on whether the impact of energy (renewable and nonrenewable) on carbon emissions is bolstered or hampered by economic growth, this paper adopts the methodical approach of Adeleye et al. (2020) and Adeleye and Eboagu (2019). The growth-energy relation is indicated by the interaction of *PC* with each of *RENW* and *ENU*, and the explicit models are specified as:

$$\begin{aligned} \ln CO2PC_{it} &= \gamma_0 + \gamma_1 \ln PC_{it} + \gamma_2 \ln RENW_{it} \\ &+ \gamma_3 \ln ENU_{it} + \gamma_4 \ln(PC * RENW)_{it} + e_{it} \end{aligned} \quad (2)$$

$$\begin{aligned} \ln CO2PC_{it} &= \varphi_0 + \varphi_1 \ln PC_{it} + \varphi_2 \ln RENW_{it} \\ &+ \varphi_2 \ln RENW_{it} + \varphi_4 \ln(PC * ENU)_{it} + v_{it} \end{aligned} \quad (3)$$

Where γ_i and ϕ_t are the parameters to be estimated; e_{it} and v_{it} are the general error terms. To evaluate the *overall* impact of *RENW* on CO_2PC, the first differential of equation [2] is derived as:

$$\frac{\partial \ln CO2PC}{\partial \ln RENW} = \gamma_2 + \gamma_4 \ln PC \quad (4)$$

Table 3: Summary statistics

Variables	Full sample		Bangladesh		Bhutan		India	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CO_2PC	0.79	0.64	0.29	0.12	0.73	0.38	1.14	0.34
PC	1879.99	1968.55	692.16	254.88	1672.92	791.87	1140.21	486.81
RENW	3.65	1.27	3.96	0.23	4.52	0.03	3.87	0.16
ENU	375.69	144.31	162.94	34.28	277.92	101.09	453.58	86.80
Variables	**Maldives**		**Nepal**		**Pakistan**		**Sri Lanka**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
CO_2PC	1.86	0.78	0.14	0.07	0.81	0.12	0.56	0.22
PC	6604.67	1072.67	536.90	145.78	926.71	136.87	2366.88	929.02
RENW	0.66	0.51	4.50	0.03	3.91	0.08	4.16	0.09
ENU	701.35	274.98	344.74	35.27	450.60	26.72	421.02	69.06

Source: Authors' Computations. CO_2PC=Carbon dioxide emissions per capita; PC=GDP per capita; RENW=Renewable energy; ENU=Energy consumption per capita

And from Equation [3], the *total* effect of *ENU* on CO_2PC is derived as:

$$\frac{\partial \ln CO2PC}{\partial \ln ENU} = \varphi_3 + \varphi_4 \ln PC \quad (5)$$

Note, the signs of the coefficients of the interaction terms, γ_4 and ϕ_4 evaluate if the interaction of *RENW* and *ENU* with *PC* enhances or distorts the impact of either energy variant on CO_2PC. Also, given that γ_2 is expected to be negative, if $\gamma_4<0$ then *PC* enhances the "good" effect of *RENW* on CO_2PC. However, if $\gamma_4>0$ it indicates that *PC* distorts the "good" effect of *RENW*. However, if the positive sign of γ_4 is less than the negative sign of γ_2, it implies that the destabilizing impact of *PC* is not sufficient to deter the "good" effect of *RENW* on CO_2PC. On the contrary, if the positive sign of γ_4 exceeds the negative sign of γ_2, then *PC* eliminates the "good" impact of *RENW* on CO_2PC. Correspondingly, since ϕ_3 is expected to be positive if $\phi_4>0$ then *PC* worsens the "bad" effect of *ENU* on CO_2PC. However, if $\phi_4<0$ it shows that *PC* reduces the "bad" effect of *ENU*. However, if the negative sign of ϕ_4 is less than the positive sign of ϕ_3, then the improving-impact of *PC* is not sufficient to eliminate the "bad" effect of *ENU*. On the contrary, if the negative sign of ϕ_4 exceeds the positive sign of ϕ_3, then *PC* eliminates the "bad" impact of *ENU* on CO_2PC. Finally, if $\gamma_{4,}\phi_4=0$ it is an indication that the interaction of both variables with *PC* has no significant impact on CO_2PC.

In the event of cross-sectional dependence in the data and cointegration among the variables, the Prais-Winsten regression model with panel-corrected standard errors (PCSE) which also controls for heteroscedasticity and serial correlation is used to estimate equations [1] and [2]. For robustness checks and to observe the consistency of the results, we deploy the bootstrapping ordinary least squares (BOLS) and the feasible generalized least squares (FGLS) techniques. The bootstrap technique is a nonparametric approach that allows for resampling of the data in memory with replacement (Mooney and Duval, 1993).

3.3. Empirical Approach

3.3.1. Pre-estimation checks[2]

Before engaging the econometric analyses, it becomes imperative to subject the data to some pre-estimation checks such as (1) cross-sectional dependence, (2) stationarity and (3) cointegration tests. Failure to control for cross-sectional dependence (CSD) can result in biased estimates due to high dependence across countries (Pesaran, 2004; 2015). The CSD test is suited for both balanced and unbalanced data. The null hypothesis is either strict cross-sectional independence (Pesaran, 2004) or weak cross-sectional dependence (Pesaran, 2015). Upon examination, evidence confirms the presence of CSD and the results from Stata routine *xtcdf* are shown in Table 4. Having confirmed the existence of cross-sectional dependence, the study applies the *t*-test for unit roots in heterogeneous panels with cross-section dependence, proposed by Pesaran (2003)[3]. The null hypothesis which assumes that all series are non-stationary removes dependence across the panels and the regressions are augmented with the cross-section averages of lagged levels and first-differences of the individual series using the augmented Dickey-Fuller approach (CADF). The result of the test derived from *pescadf* Stata syntax is shown in Table 4. Correspondingly, the second-generation Westerlund (2005) cointegration test suited for heterogeneous and cross-sectionally dependent panels is applied. The null hypothesis of no cointegration can be rejected if the variables are cointegrated in all the panels or some of the panels. The cointegration result generated from the *xtcointtest westerlund* Stata code is shown in Table 4.

Table 4: Pre-estimation checks

Variables	CSD	PESCADF		Westerlund
	Statistics	Level	1st Diff.	Statistic
$\ln CO_2PC$	21.511***	−1.101	−3.344***	−1.708**
LnPC	23.664***	2.722	−1.858**	
lnRENW	20.154***	−1.429	−2.460**	
lnENU	14.719***	Insufficient observations		

Source: Authors' Computations. *** and ** indicate statistical significance at the 1% and 5% levels, respectively; CO_2PC=Carbon dioxide emissions per capita; PC=GDP per capita; RENW=Renewable energy; ENU=Energy consumption per capita; CSD=Cross-sectional dependence; PESCADF=Pesaran cross-sectional augmented Dickey-Fuller

4. RESULTS AND DISCUSSIONS

4.1. Pre-estimation Tests

From Table 4, the results show the presence of cross-sectional dependence among countries since the null hypothesis of cross-sectional independence is rejected at 1% statistical level of significance. Thus, any shocks that occur in any of the South Asian countries may be easily transmitted to others. Also, for the panel unit root tests, the variables became stationary after taking their first difference at the 1%, and 5% level of significance, respectively. Due to insufficient observations, the statistics for energy use per capita could not be generated. For cointegration, evidence from Westerlund cointegration test shows that the variables are cointegrated across some panels, thus rejecting the null hypothesis of no cointegration at the 5% level.

4.2. Composite Econometric Results

Next, we probe if economic growth and each of the energy variants have any significant impact on carbon emissions. Further, the study interrogates whether economic growth boosts or slows the impact of energy (both renewable and nonrenewable) on carbon emissions. It becomes necessary to separate these two energy variants and examine their overall impact on emissions because of the preponderance of literature reporting a possible association between energy use and emissions level (Adeel-Farooq et al., 2020; Jiao, 2020; Khan et al., 2020; Nasreen et al., 2020; Nathaniel et al, 2020a; Parker and Bhatti, 2020; Rahman and Velayutham, 2020; Shaari et al., 2020; Udemba et al., 2020). We obtain the results (Table 5) from estimating equations [1], [2], and [3] using the panel-corrected standard errors technique (main) shown in columns [1] to [3], feasible generalized least squares (robustness) in columns [4] to [6] and bootstrap ordinary least squares (robustness) in columns [7] to [9]. We discuss each set of results in turns.

2 To avoid proliferation, the Tables for CSD, stationarity and cointegration tests are compressed into Table 4.

3 Due to the unbalanced nature of the sample coupled with several missing observations, we were unable to apply the cross-sectionally Im, Pesaran and Shin (IPS, 2003) test.

Table 5: Composite results (Dep. Var: lnCO2PC)

Variables	PCSE			FGLS			Bootstrap OLS		
	Main regression			Robustness checks					
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Constant	−8.1093***	19.6892***	−19.6577***	−4.3274***	28.5812***	−14.2547***	−6.4797***	26.3600***	−60.7769***
	(−10.33)	(7.10)	(−5.66)	(−3.09)	(10.30)	(−4.60)	(−3.89)	(3.87)	(−4.64)
lnPC	0.8676***	−2.2624***	2.6709***	0.5503***	−3.2186***	1.7537***	0.4760***	−3.4879***	9.3078***
	(8.48)	(−8.39)	(4.84)	(4.39)	(−11.75)	(3.60)	(4.18)	(−3.37)	(4.60)
lnRENW	−0.0149	−6.5972***	−0.1628***	−0.5605***	−8.0593***	−0.1029**	−0.3230	−8.1654***	−0.8795***
	(−0.41)	(−11.04)	(−3.37)	(−3.10)	(−14.06)	(−2.16)	(−0.89)	(−4.99)	(−3.72)
lnENU	0.1996*	0.1320	2.3577***	0.3342**	0.0651	1.5413***	0.6317***	0.7460***	10.0819***
	(1.70)	(1.40)	(3.94)	(2.48)	(0.56)	(2.83)	(5.63)	(6.12)	(4.78)
lnPC*lnRENW		0.7630***			0.9096***			0.9211***	
		(11.25)			(13.99)			(3.87)	
lnPC*lnENU			−0.3170***			−0.1807**			−1.4723***
			(−3.52)			(−2.27)			(−4.45)
No. of Obs.	134	134	134	134	134	134	134	134	134
R-Squared	0.782	0.904	0.809						
Wald Statistic	1062.01***	643.01***	600.91***	174.03***	667.15***	635.06***			
No. of Replications							50	50	50

Source: Authors' Computations. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% significance levels; panel-corrected t-stats in ( ); CO_2PC = carbon dioxide emissions per capita; PC=GDP per capita; RENW=renewable energy; ENU=energy consumption per capita

From column [1] of the main results, the coefficient of *PC* is positive and statistically significant at the 1% level. As expected, this suggests that economic growth intensifies emissions and validates earlier the position of related studies (Uddin and Wadud, 2014; Pandey and Mishra, 2016; Parker and Bhatti, 2020) and that a percentage change in growth leads to a 0.867 increase in emissions level, on average, *ceteris* paribus. This outcome is unsurprising as the spate of economic progress in South Asia is likely to drive up the level of carbon emissions. As expected, the coefficient of nonrenewable is positive and statistically significant at the 10% level and aligns with previous findings (Chen et al., 2019; Raza et al., 2019; Sharif et al., 2019; Awodumi and Adewuyi, 2020; Nathaniel et al., 2020a). Though the coefficient of renewable energy is statistically not significant, the negative outcome indicates that it is a negative predictor of emissions.

Nevertheless, when renewable energy interacts with economic growth, the *overall* outcome suggests that the growth does not mitigate the "good" impact of renewable energy on carbon emissions. In column [2], the coefficient of the interaction term (0.763), which indicates whether *PC* enhances or distorts the impact of renewable energy on CO_2PC is statistically significant at the 1% level. Since the magnitude of the positive coefficient determines the influence of economic growth, the differential[4] of −5.8342 (that is, −6.5972 + 0.763) gives the *total* effect of renewable energy on carbon emissions and shows that the positive interaction coefficient is not sufficient to dampen the "good" impact of renewable energy on carbon emissions. In order words, the emissions-reducing effect of renewable energy is sustained. This finding is a significant incursion to the literature. We, therefore, argue that there is a complementary effect of renewable energy and economic growth in South Asia. Similarly, the initial "bad" effect of nonrenewable energy on emissions is marginally reduced when interacted with economic growth. In column [3], the coefficient of the interaction term (−0.317) is statistically significant at the 1% level and evaluates that the *overall* impact of nonrenewable energy as 2.041 (that is, 2.358–0.317). This outcome shows that economic growth can slow down the harmful impact of nonrenewable energy on the emissions level. The most plausible argument, in deference to the environmental Kuznets curve (EKC) hypothesis, is that when an economy grows to a certain point, the optimal and efficient use of nonrenewable energy sources may yield "emissions-reducing" outcomes. Again, this finding is a significant contribution to the literature. To test the robustness of our results, the FGLS and BOLS techniques are deployed. The outcomes which are not significantly different from those of the PSCE shows that both economic growth and nonrenewable energy exacerbate emissions while renewable energy attenuates. Also, the overall effect of renewable energy is computed as −7.149 and −7.244; while those of nonrenewable energy are 1.361 and 8.609, respectively. Given these results, we submit that the interaction of economic growth enables the "good" effect of renewable energy. At the same time, it reduces the "bad" effect nonrenewable energy on carbon emissions. It engenders a new line of argument that the extent of economic growth cuts carbon emissions level. Therefore, economic growth is an essential determinant of carbon emissions.

4 The differential is obtained by deducting the coefficient of the interaction term from that of renewable energy.

5. CONCLUSION AND POLICY IMPLICATIONS

This paper situates the 2030 United Nations Sustainable Development Goals (SDGs) 7, 8, and 13 (United Nations, 2015) to investigate the trilemma of energy use – *"ensure access to affordable, reliable, sustainable, and modern energy for all"* (SDG 7); economic growth – *"promote sustained, inclusive and sustainable economic growth"* (SDG 8); and carbon emissions – *"take urgent action to combat climate change and its impacts"* (SDG 13). Similarly, it questions the growth-energy-emissions trilemma by presenting empirical findings which fill a lacuna in the literature. This study takes a new perspective and highlights discoveries on whether economic growth reduces the energy (renewable and nonrenewable) consumption and if its interaction with either energy variant reduces or exacerbate the level of carbon emissions. Using an unbalanced panel data sample from seven South Asian countries (Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, and Sri Lanka) covering 1990–2019, findings from the PSCE, FGLS, and BOLS techniques provide sufficient evidence that (1) renewable energy attenuates carbon emissions, (2) economic growth and nonrenewable energy intensify emissions, (3) economic growth strengthens the "good" effect of renewable energy on emissions, and (4) economic growth slows the "bad" effect of nonrenewable energy.

The complementary role of economic growth shows it to be an essential factor that predicts the level of carbon emissions. Policy implications are not far-fetched. The finding above does provide information for stakeholders in the region. At the same time, each country in the panel may strengthen its economic growth strategies aimed at reducing the level of carbon emissions. Lastly, tackling climate change and ensuring a sustainable environment (SDG13) requires that de-carbonization measures be pursued to enable a healthy environment that will reduce health impacts due to energy-related air pollution (SDG3) by 2030. Further investigation is required and may be taken up in the future.

REFERENCES

Abolhosseini, S., Heshmati, A., Altmann, J. (2014), The Effect of Renewable Energy Development on Carbon Emission Reduction: An Empirical Analysis for the EU-15 Countries. IZA Discussion Papers, No. 7989.

Adams, S., Nsiah, C. (2019), Reducing carbon dioxide emissions; does renewable energy matter? Science of the Total Environment, 693, 133288-133288.

Adedoyin, F.F., Nathaniel, S., Adeleye, N. (2020), An investigation into the anthropogenic nexus among consumption of energy, tourism, and economic growth: Do economic policy uncertainties matter? Environmental Science and Pollution Research, 28(3), 2835-2847.

Adeel-Farooq, R.M., Raji, O., Adeleye, B.N. (2020), Economic growth and methane emission: testing the EKC hypotheses in ASEAN economies. Management of Environmental Quality, 32(2), 1-13.

Adeleye, B.N., Adedoyin, F.F., Nathaniel, S. (2020), The criticality of ICT-trade nexus on economic and inclusive growth. Information Technology for Development, 27, 1-22.

Adeleye, N., Eboagu, C. (2019), Evaluation of ICT development and economic growth in Africa. NETNOMICS: Economic Research and Electronic Networking, 20(1), 31-53.

Adu, D.T., Denkyirah, E.K. (2017), Economic growth and environmental pollution in West Africa: Testing the Environmental Kuznets Curve hypothesis. Kasetsart Journal of Social Sciences, 30(2017), 8-15.

Afridi, M.A., Kehelwalatenna, S., Naseem, I., Tahir, M. (2019), Per capita income, trade openness, urbanization, energy consumption, and CO_2 emissions: An empirical study on the SAARC Region. Environmental Science and Pollution Research, 26(29), 29978-29990.

Ali, H.S., Law, S.H., Zannah, T.I. (2016), Dynamic impact of urbanization, economic growth, energy consumption, and trade openness on CO_2 emissions in Nigeria. Environmental Science and Pollution Research, 23(12), 12435-12443.

Ali, W., Abdullah, A., Azam, M. (2017), Re-visiting the environmental Kuznets curve hypothesis for Malaysia: Fresh evidence from ARDL bounds testing approach. Renewable and Sustainable Energy Reviews, 77(2017), 990-1000.

Al-Mulali, U., Ozturk, I., Solarin, S.A. (2016), Investigating the environmental Kuznets curve hypothesis in seven regions: The role of renewable energy. Ecological Indicators, 67, 267-282.

Apergis, N. (2016), Environmental Kuznets curves: New evidence on both panel and country-level CO_2 emissions. Energy Economics, 54, 263-271.

Asumadu-Sarkodie, S., Owusu, P.A. (2017), Carbon dioxide emissions, GDP per capita, industrialization and population: An evidence from Rwanda. Environmental Engineering Research, 22(1), 116-124.

Awodumi, O.B., Adewuyi, A.O. (2020), The role of nonrenewable energy consumption in economic growth and carbon emission: Evidence from oil producing economies in Africa. Energy Strategy Review, 27, 100434.

Aye, G.C., Edoja, P.E. (2017), Effect of economic growth on CO_2 emission in developing countries: Evidence from a dynamic panel threshold model. Cogent Economics and Finance, 5(1), 1379239.

Chen, Y., Wang, Z., Zong, Z. (2019), CO_2 emissions, economic growth, renewable and non-renewable energy production and foreign trade in China. Renewable Energy, 131, 208-216.

Chikaraishi, M., Fujiwara, A., Shinji, K.S.P., Komatsu, S., Kalugin, A. (2015), The moderating effects of urbanization on carbon dioxide emissions: A latent class modeling approach. Technological Forecasting and Social Change, 90(Part A), 302-317.

Churchill, S.A., Inekwe, J., Ivanovski, K., Smyth, R. (2018), The environmental Kuznets Curve in the OECD: 1870-2014. Energy Economics, 75(2018), 389-399.

Destek, M.A., Sinha, A. (2020), Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic co-operation and development countries. Journal of Cleaner Production, 242, 118537.

Egbetokun, S., Osabuohien, E., Akinbobola, T., Onanuga, O., Gershon, O., Okafor, V. (2020), Environmental pollution, economic growth and institutional quality: Exploring the nexus in Nigeria quality. Management of Environmental Quality: An International Journal, 31(1), 18-31.

EIA. (2019), International Energy Outlook 2019: With Projections to 2050. US Energy Information Administration. Available from: http://www.eia.gov/ieo.

Ejuvbekpokpo, S.A. (2014), Impact of carbon emissions on economic growth in Nigeria. Asian Journal of Basic and Applied Sciences, 1(1), 15-25.

Hasnisah, A., Azlina, A.A., Taib, C.M.I. (2019), The impact of renewable energy consumption on carbon dioxide emissions: Empirical evidence from developing countries in Asia. International Journal of Energy Economics and Policy, 9(3), 135-143.

IEA. (2019a), Southeast Asia Energy Outlook 2019. International Energy Agency. Available from: http://www.iea.org.

IEA. (2019b), World Energy Outlook 2019. International Energy Agency. Available from: http://www.iea.org.

Jiao, Z. (2020), Consumption-based carbon emissions and international trade in G7 countries: The Role of environmental innovation and renewable energy. Science of the Total Environment, 2020, 138945.

Khan, H., Khan, I., Tien, T. (2020), The heterogeneity of renewable energy consumption, carbon emissions and financial development in the globe : A panel quantile regression approach. Energy Reports, 6, 859-867.

Li, K., Lin, B. (2015), Impacts of urbanization and industrialization on energy consumption/CO_2 emissions: Does the level of development matter? Renewable and Sustainable Energy Reviews, 52, 1107-1122.

Mooney, C.Z., Duval, R.D. (1993), Bootstrapping: A Nonparametric Approach to Statistical Inference. Newbury Park, CA: Sage.

Nasreen, S., Mbarek, M.B., Atiq-ur-Rehman, M. (2020), Long-run causal relationship between economic growth, transport energy consumption and environmental quality in Asian countries: Evidence from Heterogeneous Panel Methods. Energy, 192, 116628.

Nathaniel, S., Barua, S., Hussain, H., Adeleye, N. (2020a), The determinants and interrelationship of carbon emissions and economic growth in African economies: Fresh insights from static and dynamic models. Journal of Public Affairs, e2141, 1-15.

Nathaniel, S.P., Adeleye, N., Adedoyin, F.F. (2020b), Natural resource abundance, renewable energy, and ecological footprint linkage in MENA countries. Estudios de Economia Aplicada, 39-2, 1-16.

Nguyen, K.H., Kakinaka, M. (2019), Renewable energy consumption, carbon emissions, and development stages: Some evidence from panel cointegration analysis. Renewable Energy, 132, 1049-1057.

Osabuohien, E.S., Efobi, U.R., Gitau, C.M.W. (2014), Beyond the environmental Kuznets Curve in Africa: Evidence from panel cointegration. Journal of Environmental Policy and Planning, 16(4), 517-538.

Osmani, S.R. (2018), Socio-economic Development in South Asia. United Nations University.

Pandey, S., Mishra, M. (2016), CO_2 emissions and economic growth of SAARC countries: Evidence from a panel VAR analysis. World Journal of Applied Economics, 1(2), 23-33.

Parker, S., Bhatti, M.I. (2020), Dynamics and drivers of per capita CO_2 Emission in Asia. Energy Economics, 89, 1-11.

Pata, U.K. (2018), Renewable energy consumption, urbanization, financial development, income and CO_2 emissions in Turkey: Testing EKC hypothesis with structural breaks. Journal of Cleaner Production, 187(2018), 770-779.

Pesaran, M.H. (2004), General Diagnostic Tests for Cross Section Dependence in Panels. University of Cambridge, Faculty of Economics, Cambridge Working Papers in Economics, No. 0435.

Pesaran, M.H. (2015), Testing weak cross-sectional dependence in large panels. Econometric Reviews, 34(6-10), 1089-1117.

Pimentel, D., Herz, M., Glickstein, M., Zimmerman, M., Allen, R., Becker, K., Evans, J., Hussain, B., Sarsfeld, R., Grosfeld, A., Seidel, T. (2002), Renewable-energy-article-pimental. BioScience, 52(12), 1111-1120.

Rahman, M.M., Saidi, K., Mbarek, M.B. (2020), Economic growth in South Asia: The role of CO_2 emissions, population density and trade openness. Heliyon, 6(5), e03903.

Rahman, M.M., Velayutham, E. (2020), Renewable and non-renewable energy consumption-economic growth nexus: New evidence from South Asia. Renewable Energy, 147, 399-408.

Raza, S.A., Shah, N., Sharif, A. (2019), Time-frequency relationship between energy consumption, economic growth and environmental degradation in the United States: Evidence from transportation sector. Energy, 173, 706-720.

Saidi, K., Hammami, S. (2015), The impact of CO_2 emissions and economic growth on energy consumption in 58 countries. Energy Reports, 1, 62-70.

Sarkodie, S.A., Strezov, V. (2018), Empirical study of the environmental Kuznets Curve and environmental sustainability curve hypothesis for Australia, China, Ghana and USA. Journal of Cleaner Production, 201, 98-110.

Shaari, S., Karim, Z.A., Abidin, N.Z. (2020), The Effect of energy consumption and national output on CO_2 emission: Using a panel ARDL analysis. Sustainability, 12, 1-12.

Shahbaz, M., Jam, F.A., Bibi, S., Loganathan, N. (2016), multivariate granger causality between CO_2 emissions, energy intensity and economic growth in portugal: Evidence from cointegration and causal analysis. Technological and Economic Development of Economy, 22(1), 47-74.

Sharif, A., Raza, S.A., Ozturk, I., Afshan, S. (2019), The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: A global study with the application of heterogeneous panel estimations. Renewable Energy, 133, 685-691.

Sharma, S., Kishan, R., Doig, A. (2014), Low-carbon Development in South Asia: Leapfrogging to a Green Future.

Twerefou, D.K., Adusah-Poku, F., Bekoe, W. (2016), An empirical examination of the Environmental Kuznets Curve hypothesis for carbon dioxide emissions in Ghana: An ARDL approach. Environmental and Socio-economic Studies, 4(4), 1-12.

Uddin, M., Wadud, A. (2014), Carbon emission and economic growth of SAARC countries: A vector autoregressive (VAR) analysis. International Journal of Business and Management Review, 2(4), 7-26.

Udemba, E.N., Magazzino, C., Bekun, F.V. (2020), Modelling the nexus between pollutant emission, energy consumption, foreign direct investment, and economic growth: New insights from China. Environmental Science and Pollution Research, 27, 17831-17842.

United Nations. (2015), Sustainable Development Goals. Available from: https://www.sustainabledevelopment.un.org/?menu=1300.

United Nations. (2019), World Economic Situation and Prospects 2019. New York: United Nations.

Wahid, I.N., Aziz, A.A., Kamaludin, M., Anang, Z. (2018), The influence of energy consumption, renewable energy and economic growth on CO_2 emission in Malaysia and Indonesia. Journal of Sustainability Science and Management, (Special Issue 4), 117-131.

Westerlund, J. (2005), New Simple Tests for Panel Cointegration. Econometric Reviews, 24, 297-316.

World Bank. (2019), World Development Indicators. Available from: https://www.data.worldbank.org/data-catalog/world-development-indicators.

Xu, Q., Dong, Y.X., Yang, R. (2018), Urbanization impact on carbon emissions in the Pearl River Delta region: Kuznets Curve relationships. Journal of Cleaner Production, 180, 514-523.

Zhang, Y.J., Yi, W.C., Li, B.W. (2015), The impact of urbanization on carbon emission: Empirical evidence in Beijing. Energy Procedia, 75, 2963-2968.