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Technological Innovation, Renewable Energy and Green Growth: perspective of SAARC Countries

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ABSTRACT

The paper explores the significance of green growth as a model for sustainable economic development, resource utilization, and environmental conservation. Exploring the influence of technical innovation and clean energy usage on green growth in SAARC-4 nations from 1992 to 2020, the study employs panel data, conducting unit root and co-integration techniques. Results indicate that the variables under consideration become stationary after taking first difference, affirming their stability. Employing FMOLS and DOLS models, the research reveals a negative effect of technical advancement and Government quality on green growth, interestingly, economic growth is found to impede green growth in SAARC countries positively. In conclusion, the study advocates for increased emphasis on technological innovation to foster green growth, urging governments and policymakers to invest in and encourage the development of innovative renewable resources.

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INTRODUCTION

The existing body of literature on green growth primarily focuses on global and developed country applications, with limited attention given to the unique context of SAARC countries. Green growth is generally accepted as an economic growth-centric approach, emphasizing sustainable development that balances human development with the preservation of natural assets for continued resource provision and environmental services (OECD, 2013). Developing countries, particularly those in the SAARC region, are more reliant on natural resources, making them more vulnerable to environmental disasters. As per the OECD, the promotion of green growth has the potential to alleviate poverty, stimulate economic growth, decrease susceptibility to environmental shifts and natural disasters, bolster energy security, and ensure stable livelihoods for individuals relying on natural resources.

Numerous studies (Lee, 2011; WB, 2012; ADB/ESCAP/UNEP, 2012; OECD, 2013) emphasize the essential role of green growth in attaining growth development sustainability. It's considered economically effective and crucial for the future of developing countries (World Bank, 2012; OECD, 2013). Technological innovation is identified as a pivotal factor driving green growth, facilitating effectiveness in the production sector, and reducing the use of natural resources and climate change influence. Without technological innovation, achieving genuine sustainability in development is deemed impossible (James et al., 1978). The importance of technology and innovation has been investigated by Grover, (2013) in case of India and Padilla-Perez and Gaudin, (2014) in case of Central America and suggested that technical improvement is essential for environment friendly growth.

Green growth places a strong emphasis on green production and consumption through the discovery of those technical innovations which enhance utilization of non-fossil fuel energies (Gotschol et al. 2014., Luukkanen et al. 2019). Green technology is recognized as a successful method for boosting green economic growth, with the application of cleaner technologies considerably tumbling CO2 emissions (Sohag et al., 2019b; Yin et al., 2015). Additionally, renewable or clean energy emerges as a significant driver for improving green economic growth. Renewable energy resources are considered environmentally desirable, emitting zero or reduced carbon dioxide, making them a potential solution to climate change issues (Amini et.al., 2013; Boroojeni et. al., 2016). The usage of environment friendly energy not only diminishes pollution but also generates clean energy, resulting in fewer external costs and less environmental pollution (Gu, et.al., 2019., Lin, and Zhu, 2019a, 2019b., Alam and Murad, 2020; Sarkodie and Adom, 2018).

Diverging from conventional growth theories, contemporary economic growth literature has redirected its attention towards purposeful technological advancements as a means to accomplish a sustainable and environmentally friendly transformation. (Acemoglu, et.al. 2016, 2013., Aghion, et.al., 2016). This shift is driven by the recognition that an unregulated laissez-faire equilibrium could result in ecological risks (Acemoglu et al., 2012). Environmental taxes and patents are emphasized as crucial tools to drive technological change, decrease the use of nonrenewable resources, and increase reliance on renewables for emission reduction (Agion, et. al. 2016. Acemoglu, et. al. 2016). The growing awareness of environmental issues has prompted economies to launch green growth infrastructure, particularly in relations to the green alteration (Song, et. al. 2019).

Motivated by these considerations, the study addresses three main questions: (1) Does technical spill over facilitate Green growth? (2) Does use of clean energy promote growth associated with minimum CO2 emissions? (3) If the answers are affirmative, what measures should SAARC countries adopt to leverage technological innovation and renewable energy consumption for green growth? The study integrates these factors into a unified framework, utilizing panel FMOLS and DOLS models to investigate their role in green growth.

The present research study enrich the existent literature in the following ways: First, it fills a gap by being the first to examine technological innovation, REC, and CO2 emissions specifically in SAARC nations. Second, it underscores the effectiveness of technical progress and REC as means to shrink climate change and promote green growth. Third, the use of panel FMOLS and DOLS models addresses issues of serial correlation and endogeneity, providing unbiased, consistent, and efficient results. The findings offer valuable research insights and guidance for strengthening factors and disengaging from others in the search of global green growth.

The remainder of the paper is organized as follows: Section 2 discusses the literature review, Section 3 presents materials and methods, Section 4 contains empirical results, and Section 5 concludes with policy recommendations.

REVIEW OF LITERATURE

Rich literature is available on the influence of technical inventions, use of cleaner energy usage, and green growth. A few studies have delved into this intricate nexus, shedding light on the effects of high-tech invention and non-fossil fuel energy on green growth.

Su and Fan (2022) examined the association between innovation in renewable energy technologies, industrial structure rationalization, and green growth in China. Their findings, based on the panel of 30 cities and different provinces covering 2013-2019, highlighted that renewable energy technology innovation influence green growth positively. However, structural changes and industrial improvements showed a negative relationship with green development.

Mensah et al. (2019) focused on 28 OECD countries from 2000 to 2014, using cointegration, STIRPAT, and IPAT techniques. The outcome of their study reveals positive impression of technological innovation on sustainable growth. Similarly, Danish,et.al. (2020) discovered the importance of the use of technologies in the process of sustainable development. For BRICS countries, finding that environmental technology and renewable energy consumption promoted green growth.

Similarly, Zhang, et.al. (2017) explored the nexus between CO2 emissions and technical progress in China using SGMM model, concluding that ecological friendly technologies mitigates carbon emissions. A case study by Sohag, et.al. (2019) checked the relationship between improvement in the technical sector and non-fossil fuel energy consumption by using the ARDL model of co-integration, and concluded the both the variables impact is positive on Green growth.

Dauda, et.al. (2019) explored the influence of invention of environment friendly technologies and GDP growth on fossil gases in 18 developed and developing countries by utilizing panel data covering period 1990 to 2016. Results of their investigation indicates that innovation reduce Carbon dioxide emission in G6 countries but increased m in the MENA and BRICS nations. Another study by Yii, and Geetha, (2017) conducted a research study in Malaysia. The utilized data covering period 1971-2013, revealing a negative short-term relationship, suggesting the importance of promoting research in innovation for sustainable growth.

Bilgili, et.al. (2016) examined the dynamic influence of renewable energy consumption on carbon dioxide emissions seventeen OECD countries from 1977 to 2010, finding a negative effect on emissions. Abolhosseini,et.al. (2014) analyzed the effect of renewable energy development and technological innovation on carbon dioxide emissions in 15 European Union economies from 1995-2010, showing mitigating effects. Similar results has been obtained by Inglesi-Lotz, and Dogan, (2018) in case of Sub-Saharan Africa.

Bilan,et.al.(2019). Conducted a study on the association among cleaner energy usage growth rate on the Carbon dioxide emissions in case of European countries by utilizing data 1995- 2015, the outcome of the study indicates non-fossil fuel energy impact negatively, but growth effect is positive on fossil gas emissions. Boluk and Mert (2014) noted a 50% decrease in emissions from the consumption of energy from renewable means related to conservative means. Similar, results are obtained by Hasnisah, et.al.(2019), in 13 Asian nations from 1980-2014. Narayan, (2010), and Yue, et.al. (2013), found that growth rate of GDP trigger CO_2 emissions, emphasized that rapid economic growth is a major cause of CO_2 emissions.

In summary, the reviewed literature offers appreciated understandings into the complex relationships amid technological novelty, renewable energy depletion, and green growth. While technological innovation appears to have positive effects on green growth, renewable energy consumption demonstrates a consistent negative impact on CO2 emissions. These findings contribute to our understanding of the intricate interplay between technological advancement, energy choices, and environmental sustainability. The next section will discuss the gaps in the existing literature and the specific focus of the current study

MATERIALS AND METHODS

In the empirical examination of the influence of technological innovation, renewable energy consumption, and economic growth on green development across four SAARC countries (Bangladesh, India, Pakistan, Sri Lanka), data has been collected form World Development Indicators covering the years 1992 – 2020. CO_2 is measured in mt per capita, Patent application by resident of the countries, Renewable Energy Consumption has been measured by taking the percentage of the total. And GDP is the growth rate in precipitate unit. Conversion of data into logarithmic form was undertaken to facilitate the interpretation of coefficient estimates as elasticity of the response variable

Econometric Model

The final model used in this study to show the influence of Technology, REC growth rate on the CO_2 emissions has been developed as follow.

$$lnCO2=f\ (lnTECH, lnRE, lnGDP, lnCO2\ )\text{---}(1)$$

Equation (1) illustrates that CO_2 releases (a proxy for green growth), a commonly employed measure by researchers such as Mensah et al. (2019). Technological innovation, represented by patent data (Tang and Tan, 2013; Fei, et. Al., 2014; Albino, et. Al., 2014; Popp, et. Al., 2011; Raiser, et.al., 2017; Chen, and Lei., 2018; Mensah, et.al., 2018), REC , and per capita growth are transformed into logarithmic form. The resulting model in logarithmic form is expressed as:

$$\ln(CO2it) = \beta_0 + \beta_1 \ln(REit) + \beta_2 \ln(TECHit) + \beta_3 \ln(GDPit) + \varepsilon it\text{------- ----------------}(2)$$

Here, t and *i* (1,2,3,4) denotes panel of countries, time spam (1992-2020). εit signifies the error term, while βi reveals the coefficient of long run estimates of CO_2 releases concerning Patent, REC , and growth rate per capita. The sings of $\beta 3$ is expected to be positive for the confirmation of U- Shaped Environmental Kuznets Cuve. The expected signs for $\beta 1$ and $\beta 2$ are negative, indicating a decrease in CO2 emissions.

DK And FPP Tests

To test for the order of integration this study applied Four tests, introduced by Levin, Lin, and Chut (2002)., Im, Pesaran, and Shin (2003), Dickey, and Fuller, (1979)., and Phillips, and Perron., (1988), are applied. The results in Table 4 specify that variables under consaturation of order one i.e. I(1) This is an indications to refusal of the null hypothesis of a unit root at the non-stationary level, necessitating the proceeding with panel co-integration technique.

Co-integration Technique;

For the check of co-integration in this research study we have applied Pedroni (1999, 2004), The seven test statistics in Table-5 indicate a majority of test statistics confirming the existence of cointegrating relationships among the estimated variables in Equation 2. To verify accuracy and consistency, the Kao cointegration test is also applied, further confirming the cointegrating relationship.

Panel Fully Modified OLS and Panel DOLS;

Following the confirmation of a long-run affiliation among the panel series, it is essential to determine the size and sign of these relations. FMOLS and DOLS estimators established by Pedroni.,(2000; 2001) are employed for this purpose. These estimators, being nonparametric approaches, address issues of bias and robustness in panel data estimation. The outcomes from both the tests presented in Table-6 provide insights into the positive and statistically significant relationship of scientific novelty with CO_2 productions. However, the impact of high-tech innovation on green growth is found to be detrimental for SAARC countries. In contrast, renewable energy consumption is identified as having a beneficial and statistically significant effect on green growth. A rise in REC is allied with a reduction in CO_2 emanations, emphasizing its role in promoting green growth. Additionally, Gross domestic product has significant positive influence on CO_2 releases, suggesting that economic growth may contribute to increased emissions in SAARC countries.

EXPERIENTIAL OUTCOMES

Descriptive Statistics of variables;

Table-1 presents the statistical summary of CO_2 emissions, patents, renewable energy consumption, and monetary expansion for four SAARC states, spanning a 26-year period from 1980 to 2020. The data reveals that the mean CO2 value is 0.657, with a standard deviation of 0.354 indicating the extent of deviation from the mean. The average logarithm of patents is 5.396, accompanied by a standard deviation of 1.933. Similarly, the mean logarithm for renewable energy is 3.975, with a standard deviation of 0.186, while the mean logarithm for GDP is 8.201, with a standard deviation of 0.512. Most variables exhibit positive skewness, except for renewable energy, which demonstrates negative skewness. Additionally, the skewness values for all variables conform to a normal distribution, falling within the typical range of 0 to 3 as per Gujrati, 5th Edition

Table 1: *Descriptive statistics of variables*

	CO2	LnTECH	LnRE	LnGDP
Mean	0.657800	5.396575	3.975833	8.201966
Median	0.660488	4.783308	3.966398	8.197504
Maximum	1.727671	9.698245	4.357827	9.367843
Minimum	0.133613	2.772589	3.548095	7.231287
Std. Dev.	0.354646	1.933446	0.186283	0.512271
Skewness	0.644363	0.920725	-0.171097	0.195097
Kurtosis	3.328130	2.543959	2.557823	2.689427
Jarque-Bera	7.663423	15.59527	1.354671	1.077728
Probability	0.021672	0.000411	0.507969	0.583411
Sum	68.41123	561.2438	413.4866	853.0045
Sum Sq. Dev.	12.95472	385.0361	3.574237	27.02939
Observations	**104**	**104**	**104**	**104**

Source: World Bank (2020)

Correlation matrix;

Table-2 displays the correlation matrix for the variables under examination. Numerous studies posit that assessing correlations among variables is crucial for detecting the presence of multi-Collinearity. Multi-Collinearity is the interdepended of explanatory variables upon each other's. And more likely to yield inaccurate results, potentially leading to over fitting of the model, compared to scenarios where explanatory variables are uncorrelated (Dauod, 2017). Iyoha (2004), suggests that variables are said to be multi-Collinear is the value of Correlation Coefficient exceeds 0.85. with coefficients ranging from -1 to +1; the closer to +1 or -1, the stronger the correlation (Hinton, 2014).

Table-2 reveals that all the co-efficient values are less than 0.85 indicating the absence of multi-collinearity. Further support for the absence of multi-collinearity is provided in Table 3, where the Variance Inflation Factors (VIFs) for all variables are below 10. This reinforces the conclusion that multi-collinearity is not present among the variables under consideration.

Table 2: *Correlation Matrix of Variables*

	CO2	LnTECH	LnRE	LnGDP
CO2	1.000000			
LnTECH	0.813899	1.000000		
LnRE	-0.629162	-0.403082	1.000000	
LnGDP	0.435163	0.240705	-0.078290	1.000000

Source: Author own efforts

Table 3: *VIF'S Results*

Var	C.Variance	VIF
LnTECH	0.002310	4.624027
LnRE	0.053944	4.280684

LnGDP	0.014322	6.015996

Source: Author own efforts

The scatter plots of the dependent and independent variables presented below provide additional insights into their individual relationships. These visualizations, depicted in Figures 1-3, serve to reinforce and elaborate on the findings presented in Table 4.

According to the Figure 1 CO_2 Releases is associated positively with that of technical advancement, as technical progress takes place it will lead the damage the environment.

Environmental damage is negatively correlated with clean energy utilization as indicated by the figure 2.

Figure-3 portrays a positive correlation between CO2 emissions and growth Per Capita, meaning that growth rate will trigger the fossil gas releases.

It is imperative to note that the interpretations drawn from Figures 1-3 are preliminary, as these relationships are examined on a one-to-one level. Such analyses provide insights into the impact of individual variables, but conclusive outcomes require a more comprehensive examination through regression models. Subsequently, the outcomes of the Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) models are presented below.

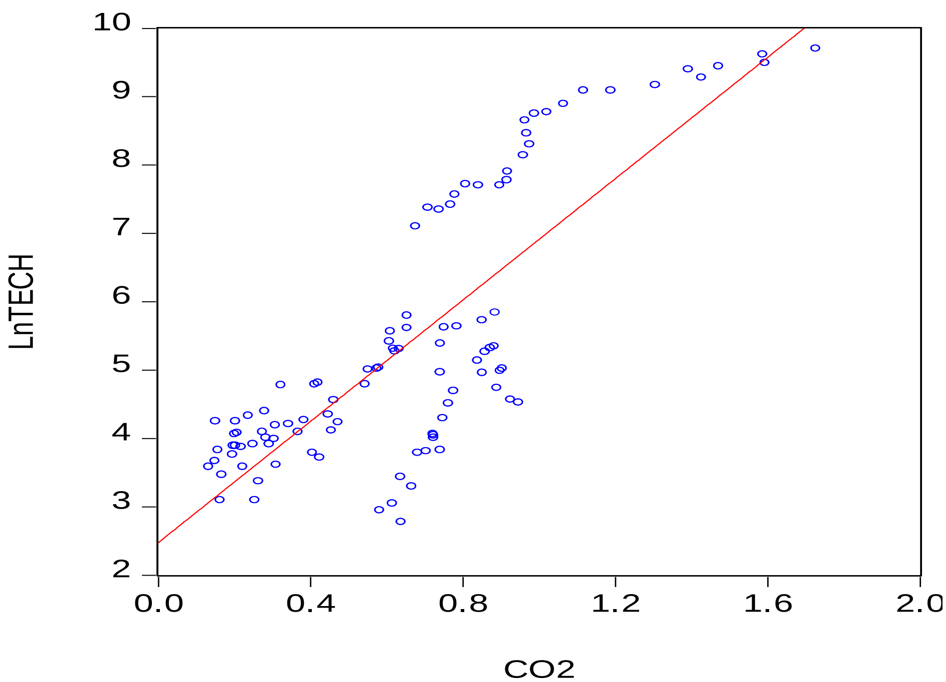

Fig 1: *Log Tech -------------- Fitted Values*

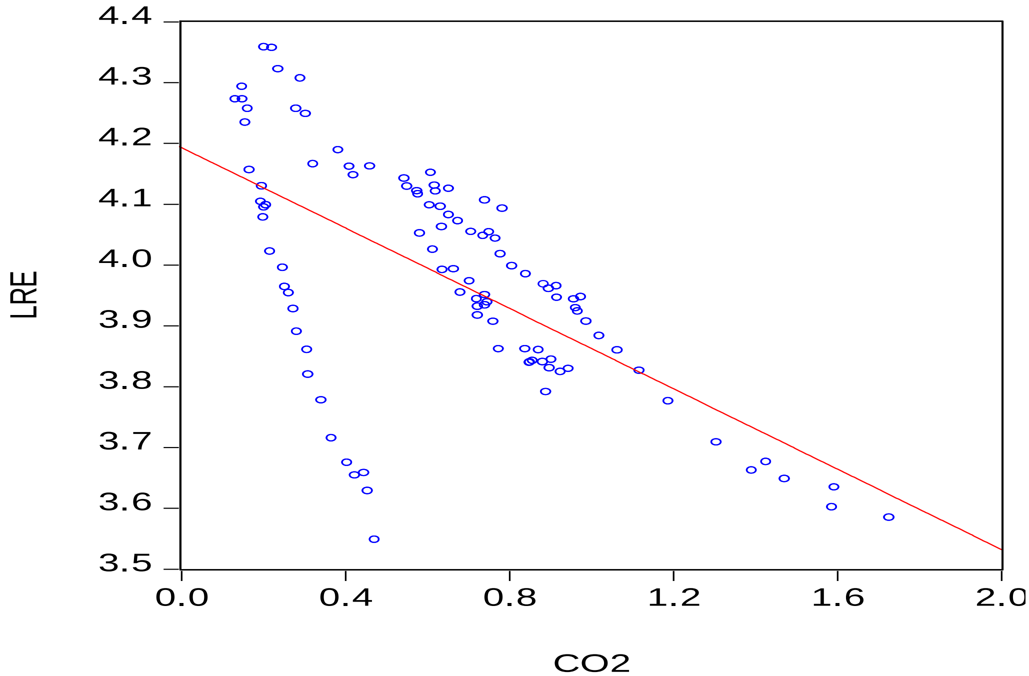

Fig 2: *Log Renewable Energy* --------- *Fitted Values*

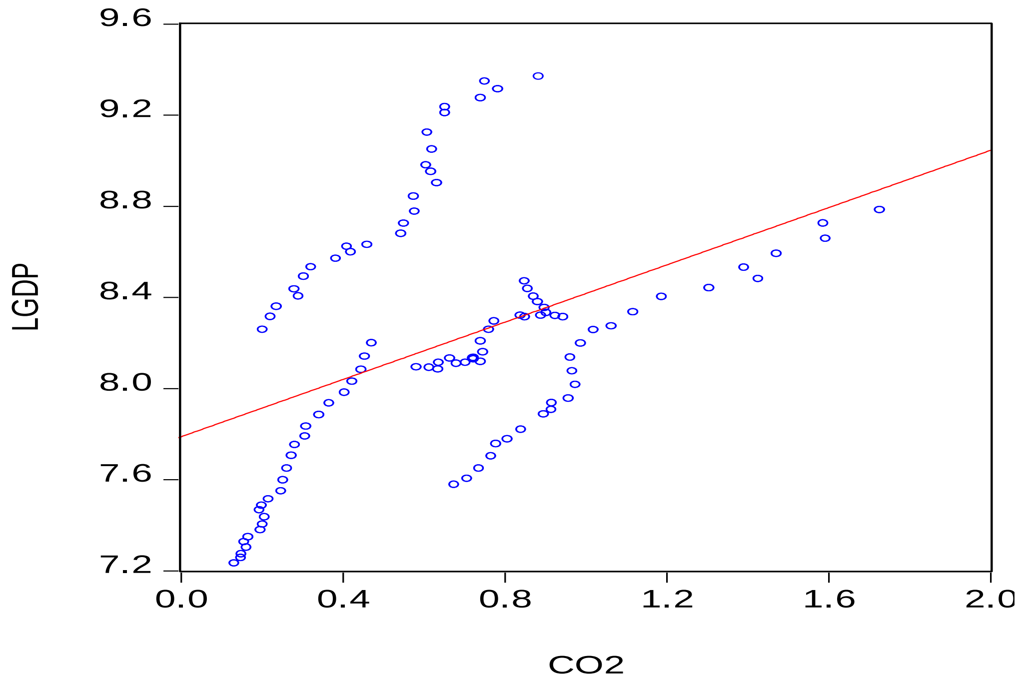

Fig 3: *Log GDP per capita* ------------- *Fitted Values*

Table 4: *Panel Unit root tests*

	I(0)				I(1)			
Variables	LLC	IPS	ADF	PP	LLC	IPS	ADF	PP
CO_2	3.204	4.708	1.186	2.153	5.328***	-5.553***	48.039***	58.823***
lnTECH	-1.195	1.068	8.443	14.4*	15.206**	14.406***	91.651***	80.436***
lnRE	2.3176	3.4912	2.4224	2.6809	5.181***	-6.186***	47.926***	47.167***
lnGDP	3.7118	5.7313	0.1902	0.1116	2.4778**	-3.0063**	25.7002**	25.9494**

Source: Author own efforts

Panel Pedroni co-integration

Table 5 presents the outcomes of Pedroni cointegration tests (Pedroni, 2001, 2004), divided into two categories (within-dimension and between-dimension). The null hypothesis of no co-ntegration has been refused by two out of four group statistics, with in the dimension group among the variables at both the 5% and 10% significance levels. Simultaneously, two out of three panel statistics also reject the null hypothesis. The outcome indicates a long-run association among these variables in the four SAARC countries.

To further validate and accuracy of these results, the Kao cointegration test developed by Kao (1999) is employed.

Table 5: *PP and Kao Co-integration results*

Dimension	**Test Statistics**	**Statistics**	**Prob**	**Kao Residual Cointegration Test**	
	Panel v-Statistic	1.251095	0.1054		ADF
	Panel rho-Statistic	-0.820421	0.2060	t-stat	P. value
	Panel PP-Statistic	-1.690463	0.0455	2.312211	0.0374
	Panel ADF-Statistic	0.117700	0.0468		
Within Dimension		**(Weighted Stat)**			
	Panel v-Statistic	1.945840	0.0521		
	Panel rho-Statistic	-0.300060	0.3821		
	Panel PP-Statistic	-1.064308	0.1436		
	Panel ADF-Statistic	0.250574	0.0989		
	Panel rho-Statistic	0.254255	0.6004		
Between dimension	Panel PP-Statistic	-0.948010	0.0116		

	Panel ADF-Statistic	0.676364	0.0506

Source: Author own efforts

Panel FMOLS and DOLS

The outcomes obtained from the Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) techniques effectively address endogeneity problems and serial correlation. The findings from both panel models, as presented in Table 5, reveal that patent, used as a measure of technological innovation, displays a positive and statistically substantial connection with CO_2 releases in the entire SAARC nations. This positive association suggests that an increase in climate change-related technology corresponds to an increased in CO_2 productions by 0.11% and 0.09%, individually. However, the lack of significance in the DOLS model is noteworthy, indicating that technological innovation may have a detrimental impact on green growth for SAARC states. This suggests that technical invention has not yet demonstrated a positive sign in enhancing green growth, possibly due to limitations in the use of certain energy generation technologies or their inability to effectively address climate change issues. These findings align with Martinez-Garcia, et.al., (2018), who stated that although technical invention leads to green growth but some may not .

Contrary to technological innovation, RE usage demonstrates a negative, substantial effect on CO_2 discharges, except in the FMOLS. This implies that increased RE consumption promotes sustainable growth in SAARC nations. A unit surge in RE consumption is linked with a declining in CO_2 discharges by 0.69% and 0.52%, respectively, underscoring the substantial importance of RE in fostering green growth. The study suggests that the transition to renewable energy can contribute to cleaner production, aligning with the findings of Mensah et al. (2019). The abundant market potential and overall benefits of renewable energy, including energy security, economic growth, and poverty eradication, make it a crucial element in reducing carbon dioxide discharges. This study indorses that SAARC countries actively promote the use of non-fossil fuel energy to achieve lower emissions.

As anticipated, GDP per capita demonstrates a positive and statistically significant impact on CO_2 productions. A one percent upsurge in market size give indications to a 0.18%, 0.38%, and 0.36% upswing in CO_2 releases, as indicated in Table 6. These results suggest that despite efforts to rise the use of RE, a substantial reduction in CO2 emissions remains elusive. The findings imply that fast Income per capita growth in high-emitting countries may result in increased energy consumption, particularly since nonrenewable energy still dominates the energy mix in these countries. Even with improvements in technologies used in the promoting efficiency and renewable energy utilization, the study highlights the challenges in achieving a significant reduction in emissions, consistent with the observations of Jiang et al. (2019).

Table 6: *FMOLS and DOLS Results*

	OLS		**FMOLS**		**DOLS**	
Variables	Co-efficient	t-stat	Co-efficient	t-stat	Co-efficient	t-stat

lnTECH	0.1107***	13.237	0.0942**	3.5705	0.0366	0.7631
lnRE	-0.6955***	-8.2278	-0.0956	-0.6027	-0.5215**	-2.2452
lnGDP	0.1808***	6.23394	0.3855**	0.8989	0.3607**	3.0144

Source: Author own efforts

CONCLUSION

This paper investigated the influence of technical improvement and renewable energy consumption on green growth in the SAARC-4 states, utilizing panel data spanning from 1992 to 2020, a timeframe selected based on data availability. Panel unit root tests and Co-integration tests were employed, with results indicating that all variables exhibits of order I(1) and long-run connections exist among the selected variables.

The outcomes obtained from FMOLS DOLS revealed a positive and statistically significant affiliation between high-tech revolution and CO_2 emissions. This suggests that scientific modernization may have a detrimental effect on green growth in SAARC countries. Conversely, the study found that renewable energy consumption positively contributes to green growth. Additionally, GDP per capita was identified as having positive effect on CO_2 discharges, indicating that economic growth may impede green growth in SAARC countries.

Based on these findings, the study proposes the following policy recommendations:

1. **Integration of Technological Innovation into Emission Reduction:**
    - Policy makers should integrate technological innovation into strategies aimed at reducing CO2 emissions, using it to facilitate waste recycling in the production process and decrease pollution.
    - Increased investment in environment friendly technologies, particularly in renewable energy, is crucial to decrease pollution and promote green growth.

2. **Transition to Renewable Energy Resources:**
    - Given that per capita growth rate inclines to increase CO_2 releases, governments should prioritize transitioning to renewable energy capitals such as solar, wind, and hydro.
    - Developing countries should improve their economic structures to effectively harness efficient and low-carbon energy sources, contributing to environmental protection.

3. **Enhancement of Data Availability and Transparency:**
    - Encourages policymakers to ensure transparency and accessibility of data related to the study's findings.
    - The statement highlights the availability of the study's data from the corresponding author upon reasonable request, promoting further research and scrutiny.

In summary, these policy recommendations aim to guide governments and stakeholders in fostering sustainable and environmentally conscious development in the SAARC-4 countries.

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