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Linkages between renewable energy, financial development, and environmental sustainability in Asian countries

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ABSTRACT

Financial development and green technologies are imperative to accomplish sustainable development goals in developed and developing economies. Therefore, this study examines the dynamic influence of renewable energy consumption, financial development, and green technology innovations on carbon dioxide emissions using selected Asian countries' data from 1990 to 2019. It applies the Cross-Sectional Augmented Distributed Lag model to address the slope heterogeneity and the cross-sectional dependency issues in our panel. The long-run results revealed that financial development increases carbon emissions while green innovation and renewable energy consumption reduce emissions. Nevertheless, the emissions mitigating effects of both variables significantly varied, and green innovation possesses a more substantial impact on emissions reduction. The short-run results also produce similar outcomes; however, their coefficient's magnitude is relatively lower. Moreover, the error correction term is significantly negative, suggesting a 25% speed of adjustment in case of any deviation from steady-state equilibrium. These results suggest integrating renewable energy and green technology innovation into the financial sector to neutralise its negative consequences.

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1. Introduction

Climate change and carbon dioxide emissions have recently brought significant attention as it influences the global ecosystem and economic or financial sector (Arioli et al., 2020). Financial development seems to contribute to fruitfully enhancing the environmental quality and easing the economic development of any country. For instance, a smooth financial system can increase ecological sustainability by

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facilitating investment, enticing foreign direct investment, and reducing investment asymmetry and uncertainty. A well-established financial system can help decrease lending costs, encourage foreign investors, and lower emissions by promoting energy efficiency (Hayat et al., 2018). It is the critical determinant of environmental quality (Charfeddine & Kahia, 2019). Moreover, the research and development activities are funded by the sound financial system of the state (Jiang & Ma, 2019). Even though various researchers have attempted to explore the association between financial development and environmental indicators, the outcomes are inconclusive (Bui, 2020). Meanwhile, financial development causes an increase in funding sources for the energy sector, resulting in decreased carbon dioxide emissions. On the flip side, it accelerates the manufacturing process, ultimately enhancing the pollutants in the atmosphere. The previous studies investigated the relationship between financial development and the environment and demonstrated its implications for improving environmental quality, but these studies only discussed its direct effect (Liu et al., 2022). Nevertheless, one of the indirect effects of financial development, for instance, energy demand and consumption, is yet ignored. Caruso et al. (2020) stressed designing effective policies to restrict the utilisation of energy sources and formulate alternative energy sources like renewable energy sources (Abid et al., 2022).

As highlighted by the current literature, the financial sector provides significant help to energy-producing firms to reduce harmful discharge (Chen et al., 2019). Green finance combines financial development and ecological safety to obtain a sustainable society by putting environmental protection at the centre of investment and protection. Green finance has many forms among participants, including investors, financial institutions, and governments. Conversely, financial development enhances energy utility through direct, business, and wealth effects (Sadorsky, 2011; Tang et al., 2022). Thus empirical findings are divided into two strands of conclusion. Tamazian et al. (2009) and Mahalik and Malik (2014) claim that financial development did not harm the environment. In contrast, Shahbaz et al. (2016), and Anwar et al. (2021b) revealed the contradictory impact of the financial sector. Given the ambiguous outcomes, more research is needed to resolve the ambiguity. Two factors are vital in reducing global carbon dioxide emissions; energy utilisation and the commitment of prime contributors to carbon dioxide emissions. For this reason, renewable energy resources are an imperative source of pollution reduction (Nathaniel & Iheonu, 2019). In 2025 the share of electricity produced from renewable energy sources will upsurge by almost 45% worldwide (International Energy Agency, 2017). The increase in the share of renewable energy is due to each country's pledge to clean energy. Zafar et al. (2019) assert that renewables are cost and ecologically effective, offering energy savings and affordable protection of the environment.

The primary cause of eco destruction is the extensive utilisation of traditional energy resources like fossil fuels (Habiba et al., 2022). The concern of greenhouse gas emissions, especially carbon dioxide emissions, is the focus of academicians and policymakers of several organisations to leave a healthy environment for coming peers. According to the statistics released by the united nations intergovernmental panel on climate change, the widespread burning of highly polluted energy sources increases carbon release by 1.9% per year. The most polluted countries discharge different kinds of heat-absorbent gases into the air. The world energy 2022 reports that the Southeast Asian economies worldwide make up more than 70% of carbon emissions. Hence, instant plans need to be implemented to control the harmful release in the said regions to achieve environmental sustainability. Although, the existing literature has examined the main determinants of ecological indicators (Anwar et al., 2021a; Chien et al., 2021). However, there are no prominent studies investigating the influence of green innovation, financial development, and renewable energy consumption on carbon emissions in Asian countries.

Lastly, clean technology advancements have played a prominent role in decreasing carbon dioxide emissions. Braun and Wield (1994) outlined the foundational theory of green technology, implying that green innovation should comprehend environmental protection, waste disposal, monitoring, recycling, and various assessment procedures. Almost 60% of global warming can be reduced through energy efficiency and renewable energy (IEA, 2013). Thus, green technology innovation is essential for every country in the world. Therefore, the implementation and distribution of green technology vary significantly from country to country, conditional on the economic and social situation of the state. Consequently, it is essential to understand how green technology innovation has influenced carbon dioxide emissions in selected Asian countries. Earlier studies emphasised the impact of clean energy or economic growth determinants on ecological safety (Habiba et al., 2022). Yet several other factors influenced the consumption of clean energy. For example, producing renewable energy resources requires advanced/green technological innovations, and well-organised research and development sector is needed to develop green innovations. Thus, a robust financial system is needed to support green advancements.

Given the above background, various contributions are made to the existing literature. First, this is the effort to explore the dynamic relationship between green technology, financial development, and renewable energy consumption on the carbon dioxide emissions in South Asian countries. Second, the implementation of green technology innovations depends on the social and economic conditions of the countries; thus, this study took a sample of diversified countries of South Asia with unique characteristics, namely Afghanistan, India, Pakistan, Srilanka, and Bangladesh, Nepal, Maldives, and Bhutan. Third, we used the advanced panel data approach to obtain the desired outcome of the study.

The remaining study is designed as follows. The second segment critically evaluates the existing work; the third section explains the data and theoretical model with the framework used in the study. The next part of the study discusses the results, and the study concludes with possible policy implications.

2. Literature review

The toxic discharge from various sources causes a hazardous impact on the environment. Amongst others, carbon emissions are believed to be the main cause of environmental pollution. Technological advances and innovations can help reduce carbon release's negative influence on the ecosystem. Hence, this section reviews previous studies that enlightened the association of carbon dioxide emissions with financial development, green innovation, and renewable energy consumption.

2.1. Renewable energy and carbon dioxide emissions

Renewable energy source contributes positively to economic growth and environmental quality (Anwar et al., 2021b). The primary renewable energy source is the natural way of producing energy for inland consumption, which causes less environmental destruction. Understanding the key welfare of renewables, the energy sources are classified into renewable and non-renewable energy sources and investigated their linkage with environmental quality. In this scenario, Apergis et al. (2010) explored the connotation between renewable and nuclear energy consumption and economic growth with carbon emissions for 19 countries from 1984 to 2007, utilising the panel error correction model. Results discovered that renewable energy mitigates carbon dioxide emissions, whereas the nuclear energy sector contributes to harm to the environment. Therefore study implies that the nuclear discharge storage facilities in the selected 19 countries ought to be effectively maintained. For the MENA countries, the energy sector affects the ecosystem badly (Farhani & Shahbaz, 2014). On the flip side, Anwar et al. (2021a) utilised the FGLS method for G7 nations and found the positive influence of clean energy sources on the atmosphere. Several studies like Jin and Kim (2018) and Inglesi-Lotz & Dogan (2018) found two-way causality between energy sources and the environment, while a negative relationship was established between the variables for 30 states and Sub-Saharan African countries, respectively. Renewable energy consumption brings unexpected inconvenience to the placement and installation of renewable sources.

On the other hand, installing renewable systems in China, exclusively solar and wind energy systems require the simultaneous use of non-renewables like fossil fuels (Sun et al., 2022). Such circumstances negated the benefits of renewables, and the goal of achieving a green economy was not accomplished. Taking economic growth as a controlling factor, studies like Ji et al. (2020), Khattak et al. (2020), and Nathaniel and Iheonu (2019) observed that the renewable energy sector promotes the sustainability of the environment in various developed and emerging countries. In the opinion of Nguyen and Kakinaka (2019), implementing the renewable energy source policy depends on the country's progression, as their study implies dissimilar outcomes for low and high-income countries. Few studies also shed light on uni-country analysis; for instance, renewable energy helps reduce Pakistan's carbon dioxide emissions (Zhang et al., 2017). Later, For India, Sinha and Shahbaz (2018) took data from 1971 to 2015 and deployed the ARDL model to enhance the significance of renewable energy sources. The parallel result has been exposed in the study by Bulut (2017) done for Turkey. Miao et al. (2022) utilised the novel econometric technique of MMQR and concluded that Malaysia's renewable energy consumption helps clean the ecosystem.

2.2. Financial development and carbon dioxide emissions

Recently, the insistence has been placed on exploring the relationship between financial development and carbon dioxide emission. Nevertheless, the experimental findings connecting financial development to various environmental degradation indicators are inconclusive. The outcomes hold ambiguity in terms of negative or positive impressions. Similarly, the results also vary for single country and panel setting analysis. In this context, Shahbaz et al. (2016) found the inverse relationship between financial development and environmental hazards in Malaysia by employing the ARDL modelling approach. The historical data from 1971 to 2011 revealed that progression in financial growth causes lowering harmful effects on the environment. In the emerging nation of Pakistan, it is observed that the rise in financial liberalisation enhances the quality of the atmosphere (Abbasi & Riaz, 2016). Conversely, the financial sector in France plays a positive role in decreasing greenhouse gas emissions in the atmosphere as development with advanced technology contributes to the betterment of ecology (Shahbaz et al., 2018). Tamazian et al. (2009) deployed the random effect panel data model for the BRICS economies and concluded that financial development decreases the selected region's carbon emissions. South Asian countries suffer from pollution as a unidirectional association is detected between financial development and poisonous emissions (Nasreen et al., 2017). The financial growth of developed and emerging countries helps reduce the region's carbon footprints (Habiba & Xinbang, 2022).

Several studies also find a positive and direct relationship between the financial sector and environmental degradation. Due to the growing financial development in China, the threat to the quality of the environment has been revealed in the study of Xing et al. (2017). Al-Mulali et al. (2015) studied the data from 129 nations and clinched that financial progress increases environmental hazards. Developing countries face environmental issues due to the rapid growth in the financial sector. Such consequences are exposed by Anwar et al. (2021a) with the help of the FMOLS method. Sehrawat et al. (2015) took historical data from 1971 to 2011 from India and explored the association between financial development and carbon dioxide emission through the ARDL and VECM approaches. The study confirms the direct relationship among the said variables. An asymmetric relationship has been found between financial indexes and ecological destruction in Pakistan in the study of Shahbaz et al. (2016). Likewise, concerning Malaysia, the study performed by Maji et al. (2017) obtained the outcomes from a conventional ARDL modelling strategy and concluded that financial development weakens the quality of the environment. The study of Usman and Makhdum (2021) proposed mixed implications of financial development on ecological footprints for BRICS-T countries. Few literatures like Chen et al. (2019), Dogan and Turkekul (2016), and Jamel and Maktouf (2017) highlight an insignificant correlation between financial progress and carbon dioxide emissions.

2.3. Green innovation and carbon dioxide emissions

Green innovations are technology advancements that reduce carbon dioxide emissions and minimise environmental hazards. It is a well-founded way to control the harmful discharge in the atmosphere and can actively enhance economic growth. Several studies demonstrate that green innovation is the healthy determinant of explaining environmental degradation in various economies. Lee and Min (2015) inspected the tenyear data of Japanese production companies to observe the influence of green investment on carbon dioxide emissions. The study outcomes showed the inverse relationship between green advancement and carbon traces in Japan. Likewise, similar results were obtained for Malaysia in the study of Yii and Geetha (2017), implying that advancements in the manufacturing sector tend to improve the ecosystem in the country. The author's employed an error correction model to meet the required objective of the study. In the scenario of Turkey, the novel Bootstrap Autoregressive distributed lag model is exploited and detected that the enhancement of green innovations/investments in the country increase the quality of the environment (Shan et al., 2021). Furthermore, at the regional level, it has been found that diverting conventional manufacturing procedures to advanced green technology helps to improve pollution in 30 provinces of China (Zhang et al., 2017). Utilising the various panel data techniques on the data points of the OECD regions, Hashmi and Alam (2019), Ganda (2019), and Paramati et al. (2021) concluded that the implication of green technology innovations in the industrial sector reduces the hazardous releases in the environment.

Indeed, green innovation poses a positive impact on environmental health, but there are several early studies claiming its negligible impact. Using energy technology patents as a proxy of green innovation for provinces of China, Wang et al. found an insignificant association with carbon emissions. Green innovation can indirectly affect the ecological output and boost the clean ambiance in Italy (Weina et al., 2016). In the same vein, the study by Du et al. (2019) announced that the induction of green innovations in the industrial sector does not impact lower-income countries.

The above-highlighted literature shows that the empirical outcomes of the various determinants of carbon dioxide emissions are inconclusive. Moreover, several studies focussed on G7, BRI, G20, or MENA countries, but none chose the South Asian region. It has also been observed that analysing green innovation, financial development, and renewable energy consumption are region-restricted, and nonlinearity exists among them. Thus, to compensate for the explained gap, the current study contributes to the literature in numerous ways.

3. Methodology

3.1. Data and theoretical model

This study accounts for South Asian countries; India, Pakistan, Srilanka, Bangladesh, Nepal, Maldives, and Bhutan. The timeframe has been decided on the availability of data period from 1990–2019. The South Asian region has attracted researchers' attention due to its volatile financial market. Since the countries are emerging thus, achieving economic growth is the primary concern leading to environmental degradation. Land deprivation, water depletion, and pollution hurt environmental sustainability (Lee et al., 2022). Therefore the South Asian country exploring the dynamic linkage between financial development, green innovation, renewable energy, and economic growth seems essential. The details of variables and sources are discussed in Table 1. The functional form of the model highlighting the emission of carbon emissions for this study is;

Table 1. Data variables and sources.

Variables	Symbol	Measurement	Data sources
Carbon emissions	CE	Matric Tons Per Capita	GCA
Renewable energy consumption	RE	Percentage of total final energy consumption	WDI
Financial development	FD	Cumulative Financial Development Index measures the depth, access, and efficiency of financial institutions' and financial markets.	IMF
Green technology innovation	GI	Environmental Technologies % of Total Technologies.	OECD Stat.
Economic growth	EG	Constant (2010) USD Per Capita	WDI

GCA, WDI, IMF denotes the Global Carbon Atlas, International Monetary Fund, and World Development Indicators (2021).
Source: Author's estimations.

$$CO_{2\ jt} = f(FD_{jt}^{\alpha 1},\ GI_{jt}^{\alpha 2},\ RE_{jt}^{\alpha 3}, EG_{jt}^{\alpha 4}) \tag{1}$$

The study took the secondary data, where CO_2 is the experimental variable, and financial development (F.D.), Green innovation (G.I.), and Renewable energy (RE) are the independent variable, while economic Growth (E.G.) serves as the control variable. These variables were used as natural logarithmic per capita. According to the pollution-haven hypothesis, financial development is taken as the independent variable to confirm its effect on carbon dioxide emission. Thus, the pollution haven hypothesis confirmed that in South Asian countries, financial development has a significant and positive effect on carbon emissions. Financial institutions often fund economic activities, and economic prosperity causes an increase in energy consumption. Recent studies (Bilgili et al., 2016; Inglesi-Lotz & Dogan, 2018) contemplate renewable energy as essential in diminishing carbon dioxide emissions. Green technology is expected to decrease carbon emissions in the region. The current study believes that renewable energy negatively affects carbon dioxide emissions in South Asian countries, similar to the previous studies' results. The flow of association between the variables is also presented in Figure 1. The study comprised the following log-linear empirical model;

$$lnCO_{2\ jt} = \alpha_1 \ln FD_{jt} + \alpha_2 \ln GI_{jt} + \alpha_3 \ln RE_{jt} + \alpha_4 \ln EG_{jt} + \in_{jt} \tag{2}$$

where α's is the coefficients, $\in_{jt}$ is the error term of this model, and t & j represents the time from 1990 to 2019 and cross-sectional units (sample countries).

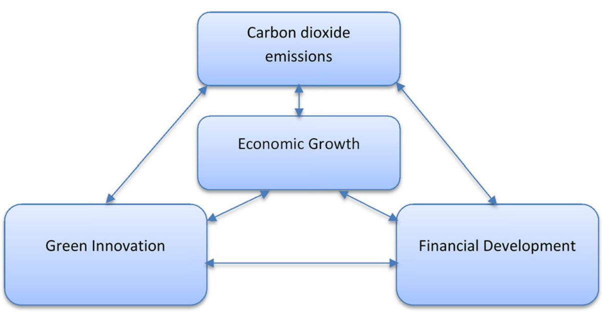

Figure 1. Graphical illustration (Source: Authors illustration).

3.2. Econometric modeling framework

The present study utilises advanced econometrics techniques. The slope coefficients homogeneity test (SCH) and the cross-section independence test (CSI) are applied in the preliminary step. Khan et al. (2020) and Ulucak and Khan (2020) hypothesised that ignorance of this problem may lead to unpredictable and biased estimates. Baltagi and Hashem Pesaran (2007) employed the Slope Coefficient Homogeneity (SCH) test with the effective premise that these slope coefficients retain a homogeneity assumption. Whereas the Cross Section Independence (CSI) tests of Pesaran (2007) account for the internal economic crisis in the form of global financial crises 0f 2007–2008, Asian financial crises of 1997, global oil prices shocks, and the recent pandemic of COVID-19. The equation for the SCH test is as follows,

$$\Delta_{SCH} = N^{\frac{1}{2}}\ (2K)^{-\frac{1}{2}}\left(\frac{1}{N}\ S - k\right) \tag{3}$$

$$\Delta_{ASCH} = N^{\frac{1}{2}}\ \left(\frac{2K(T-k-1}{T+1})\right)^{-\frac{1}{2}}\left(\frac{1}{N}\ S - 2k\right) \tag{4}$$

Here, Δ_{SCH} *and* Δ_{ASCH} are the homogenous slope coefficient and adjusted slope coefficient, respectively.

Due to the panel data's cross-sectional dependence and slope heterogeneity, the first-generation unit root or stationarity testing like Levin et al. (2002) and Im et al. (2003) are not considered in the study. Therefore, the extension of M. H. Pesaran (2007), known as the cross-section Im, Pesaran & Shin (IMPS) or (CSIMPS) test, has been employed. This test is powerful against the non-homogeneity of slope coefficients and cross-section dependence. Specifically, the dependence on the cross-section is overthrown by adding the lags and creating a first difference averages series from the cross-section expansion. The general equation of the CSIMPS test is specified as,

$$\Delta\ Y_{jt=\ \beta_i} + \ \beta_i Y_{j\ \ t-1} + \ \beta_i \bar{x}_{t-1} + \sum_{k=0}^{p} \beta_{ik}\ \Delta\ \overline{Y}_{t-1} + \sum_{k=1}^{p} \beta_{ik}\ \Delta\ \overline{Y}_{t-1} + \ \mu_{it} \tag{5}$$

In this equation $\overline{Y}_{t-1}$ and $\Delta\ \overline{Y}_{t-1}$ denoted as lagged and averages of the first difference. So the test statistics of the CSIMPS test with the null hypothesis in support of non-stationary while the alternate hypothesis supports stationarity as:

$$\widehat{CSIMPS} = \ \frac{1}{N}\sum CADF_i \tag{6}$$

The CADF stands for the Cross-section Augmented Dickey-Fuller, also utilised with the above equation.

The error correction-based test (Westerlund & Edgerton, 2007) has been employed to evaluate the long-run cointegration relationship between carbon dioxide emission, financial development, green innovation, Renewable energy, and economic growth. In comparison with Pedroni and Kao's cointegration tests, this test was found to be a robust approach (Khan et al., 2020). Furthermore, this test is beneficial to employ where non-homogeneous slope coefficients exist and residuals are cross-sectionally dependent. The general equation of this test can be written as,

$$G_t = \frac{1}{N}\sum_{j-1}^{N}\frac{\grave{\theta}_j}{SE(\grave{\theta}_j)} \tag{7}$$

$$G_a = \frac{1}{N}\sum_{j-1}^{N}\frac{T\grave{\theta}_i}{\grave{\theta}_i\ (1)} \tag{8}$$

$$P_t = \frac{\grave{\theta}}{SE(\grave{\theta})} \tag{9}$$

$$P_\alpha = T\grave{\theta} \tag{10}$$

where Eqs. (7) and (8) represent the group means statistics, and Eqs. (9) and (10) show the panel statistics. The null hypothesis with no cointegration has been tested against the cointegration does not exist.

3.2.1. Cross-Sectional Augmented Distributed Lag (CS-ARDL) model

This paper uses the CS-ARDL approach suggested by Chudik and Pesaran (2015) to investigate long- and short-run estimates. This test carries out function reliably and powerful against the mean group, augmented mean group, pooled mean group, and commonly correlated effect mean group. This test addresses the heterogeneous slope coefficients, non-Stationarity with diverse integration orders, the dependence of cross-section and endogeneity, and combat with unobserved common factors that not only impact significantly but get over this issue may cause biasedness in estimation (Khan et al., 2020). The general equation of the CS-ARDL model is as follows,

$$CO_{2\,jt} = \gamma_0 + \sum_{j=o}^{q}\rho_{jt}CO_{2,\,t-j} + \sum_{j=0}^{q}\grave{\sigma}_{jt}R_{t-j} + \sum_{j=0}^{q}\tau_{jt}\overline{Z}_{t-j} + \varepsilon_{jt} \tag{11}$$

Here, $\overline{Z}_t = \left(\Delta CO_{2\ jt},\ \overline{R}_t\right)$ and $R_{jt} = (FD_{jt},\ GN_{jt},\ RE_{jt}, EG_{jt})$ i.e., R shows financial development, green innovation, renewable energy, and economic growth. Eberhardt (2012) developed the approach of an augmented mean group that has been employed to acquire the robustness of the estimates. Far from the earlier approaches like pooled mean group and mean group, these tests grant robustness in their outcomes, even supporting the heterogeneity, non-Stationarity and cross-section dependence among the individual units.

Table 2. Cross-sectional dependence test results.

	Pesaran CSD	
Variables	Stat.	Prob.
CE	20.410***	0.000
RE	14.754***	0.000
FD	35.218***	0.000
GI	15.439***	0.000
EG	25.050***	0.000

Source: Author's estimations.
Note: *** indicates the significance level at 1%.

4. Results and discussion

In this section, the empirical outcomes are presented and discussed with their implications. The preliminary analysis has been done to ensure that cross sections are dependent and slopes are heterogeneous. Keeping the importance of these results, the second generation unit root tests have been deployed to identify the order of integration of the variables under study. The stationary series was then used to obtain robust estimates using the CS-ARDL modelling approach.

The outcomes of Pesaran tests of cross-sectional dependence are displayed in Table 2, implying cross-section dependence among the units. The null hypothesis of no cross-sectional dependence has been rejected at a 1% significance level. Due to external factors like globalisation, structural breaks, and financial assimilation, the cross-sections are dependent on the selected sample.

The slope homogeneity test retrieved the outcomes in Table 3. The heterogeneous effect of the slopes is evident at a 1% significance level.

The cross-section dependence and heterogeneity effect in the slopes motivate the study to apply the second-generation unit root test. The stationarity of the variables has been checked through CIPS and CADF unit root tests (Table 4). The null hypothesis of non-stationarity/presence of unit root in the series is rejected at 1% and 5% levels of significance. Thus outcomes conclude that all the variables have unit root concerns at levels while at the first difference, the series get stationery.

To establish the long-run relationship between the variables in the presence of cross-section dependence and slope heterogeneity, the second-generation Westerlund (2007) cointegration test is applied. The results of panel and group test statistics are presented in Table 5. The group test Gt and panel statistics Pt are significant at one a % significance. Therefore the long-run relationship is evident in the outcomes of the cointegration test and concludes that renewable energy consumption, financial development, green innovation, economic growth, and carbon dioxide emissions are cointegrated.

Table 3. Slope homogeneity test results.

Model: $CE_{it} = f\ (RE_{it}\ ,\ FD_{it}\ ,\ GI_{it},\ EG_{it})$			
Delta		Adjusted delta	
Stat.	Prob.	Stat.	Prob.
12.530***	0.0000	9.165***	0.0000

Source: Author's estimations.
Note: *** indicates the significance level at 1%.

Table 4. CIPS and CADF unit root test.

	CIPS		CADF	
Variables	I(0)	I(1)	I(0)	I(1)
CE	−1.545	−3.438***	−1.010	−3.128***
RE	−1.420	−4.125***	−1.255	−3.761***
FD	−1.790	−3.720***	−2.147	−3.527***
GI	−0.635	−2.760***	−1.314	−2.659**
EG	−1.079	−2.979**	−0.990	−2.685**

Source: Author's estimations.
Note: ***, ** indicate the significance level at 1%, and 5%, respectively.

Table 5. Westerlund (2007) cointegration test results.

Model: $CE_{it} = f\ (RE_{it}\ ,\ FD_{it}\ ,\ GI_{it},\ EG_{it})$		
Statistics	Values	P-values
Gt	−4.846***	0.015
Ga	−9.830	0.740
Pt	−8.248***	0.001
Pa	−12.369	0.644

Source: Author's estimations.
Note: *** indicates the significance level at 1%.

Table 6. CS-ARDL test results.

Model: $CE_{it} = f\ (RE_{it}\ ,\ FD_{it}\ ,\ GI_{it},\ EG_{it})$				
	Short-run		Long-run	
Variables	Coeff.	t-value	Coeff.	t-value
RE	−0.058*	−1.750	−0.121**	−2.319
FD	0.140**	2.351	0.205**	2.087
GI	−0.046*	−1.843	−0.185**	−2.120
EG	0.375**	2.106	0.392**	2.416
ECM (-1)	−0.250***	−4.238	-	-

Source: Author's estimations.
Note: ***, **, * indicates the significance level at 1%, 5%, and 10%, respectively.

The last step is to obtain long and short-run estimates to devise the outcomes' implications and the CS-ARDL model's applicability to the series. Table 6 displays the results of the Cross-Sectional Autoregressive Distributed Lag (CS-ARDL) model. The long-run estimates of financial development show a positive and significant impact at a 5% level of significance on carbon dioxide emissions of the South Asian economies. The coefficient associated with financial development implies that 1% increase in financial development causes a 0.140% enhancement in carbon dioxide emissions. Such findings are consistent with the fact that financial development promotes foreign direct investment resulting in the prosperity of economic growth. This financial inclusion characteristic indirectly influences carbon emissions through energy consumption in South Asian countries. Specifically, financial development stimulates the purchase of energy-consumed products like intensive energy-consumed transportation and household electrical appliances. Therefore the individual consumption of energy has enhanced, harming the environmental quality. The results of Shahbaz et al. (2016) and Anwar et al. (2021a) are similar to the current findings concerning financial development.

The estimated long-run coefficient of renewable energy is negative and significant, depicting that increased renewable sources results in decreased carbon dioxide emission in South Asian countries. The outcomes of the long-run estimates favour using renewable energy sources to achieve environmental sustainability in the region. Renewable energy sources do not contribute to emitting carbon dioxide and progressing economic development without hurting the ecosystem. The policymakers must devise policies to install wind, hydropower, and solar energy sources in South Asian countries to restrict carbon emissions at industrial and household levels. There is a substantial need to promote renewable energy sources in the manufacturing sector to improve the region's economic growth without harming the environment. Zhang et al. (2017) revealed that renewable energy sources negatively impact carbon dioxide emissions in Pakistan, which is consistent with the present study's estimates. Energy consumption should be restricted by implementing expensive carbon-based energy products in South Asian states. The outcomes are also consistent with the study of Sinha and Shahbaz (2018). Table 6 also furnishes that green innovation is negatively associated with carbon dioxide emission in the long run, indicating that a 1% enhancement in implementing green innovations is a decrease of 1.843% in harmful emissions in the region. The estimated coefficient further demonstrates that the manufacturing process must be shifted to green technology in South Asian countries to achieve sustainable development. The technology based on green advancements is more effective than the conventional tools of the manufacturing industry because of the low energy consumption. Results also suggest that energy usage in maintaining business should divert to sources based on green technology. Eco-friendly technology helps reduce carbon emissions, as shown by the study by Lee and Min (2015), Shan et al. (2021), and Yii and Geetha (2017).

It is well documented that financial development accelerates the funding sources to boost the economy of any country via foreign direct investments. These acts pose a threat to the environment due to the excessive consumption of energy. Economic growth is positive and highly significant in the long run, indicating that economic progress leads to ecosystem destruction in South Asian countries. Thus, strict policies must be formed to utilise the country's finance to develop green technology and obsolete the traditional manufacturing modes to save energy sources.

The dilemma of the short-run coefficients is not much different from the long-run estimates. The error correction term is negative and highly significant, revealing that a 0.25% speed of adjustment is required to establish the long-run equilibrium relationship among the variables. Renewable energy and green innovation are saving the environment as a negative and significant association established with carbon emissions in the short-run. Habiba et al. (2022) also concluded the same inference related to renewable energy consumption. Financial development and economic growth pose a threat to the ecosystem of South Asian countries as estimated coefficients are positive in magnitude and highly significant statistically. It is also noteworthy that the degree of impact in the short run compared to the long-run estimated coefficients is low.

Table 7 reports the robustness results obtained to check the reliability of the estimated coefficients through the CS-ARDL model. The associated coefficients of the

Table 7. Robustness check.

Model: $CE_{it} = f\ (RE_{it}\ ,\ FD_{it}\ ,\ GI_{it},\ EG_{it})$		
	AMG	
Variables	Coeff.	t-value
RE	−0.117**	−2.170
FD	0.223**	2.325
GI	−0.144**	−2.409
EG	0.378**	2.519
Constant	0.842	1.415

Source: Author's estimations.
Note: ***, ** indicate the significance level at 1%, and 5%, respectively.

explanatory variable highlight the same conclusion drawn through the C-ARDL modelling approach. Financial development and economic growth are negatively correlated, whereas green innovation and renewable energy resources positively influence carbon emissions.

5. Conclusions and policy implications

This study discovers the dynamic influence of green innovation, financial development, and renewable energy consumption on carbon dioxide emissions in South Asian countries from 1990 to 2019. Advanced panel data techniques have been employed to accomplish the required objectives, including slope heterogeneity and cross-sectional dependency tests, second-generation unit root tests and cointegration tests, and CS-ARDL modelling frameworks. The long-run estimates suggest the negative impact of renewable energy and green innovation on carbon emissions of South Asian countries. At the same time, financial development and economic growth accelerate environmental degradation. Similar results are endorsed by alternative estimators and offer the following policy implications;

1. The conventional products and strategies have been superseded by novel and effective techniques that enhance environmental administration through green technological innovations transforming the older production techniques and ultimately ensuring economic growth. Authorities are less attracted to continuous eco-friendly policies and have minimum internal social pressures, even though clean, innovative measures are helpful in reducing carbon emissions. Thus, advanced eco-friendly strategies are needed at every level of the domestic sector, including transportation, to diminish the factors enhancing emissions. Solar and wind energy categorised under the umbrella of green technology, can also be utilised to minimise household carbon footprints. The quantification of the spoiling effect needs to be observed, which has resulted in the expansion of technologies with time. Furthermore, conventional techniques should be replaced with innovative strategies in business and financial matters through accurately inculcating biodegradable policies, which has become an absolute necessity in the contemporary scenario. In short, by embracing modern energy plans and government funding to companies and investors, green transformation can be achieved.

2. Energy is the second largest contributor to carbon emissions and a key economic growth source. To reduce emanations by traditional energy consumption practices and establish new renewable and merger-able energy alternates, importing upgraded equipment, research and development, and industrialisation in the production sector is inevitable. Eco-friendly technology and minimising conventional fossil concentrated energy sources should be the top priority of highly polluted countries to reduce environmental issues. High energy consumption habits and dependency levels can be altered by creating awareness through electronic and social media and government-led, national eco-friendly strategies. Decision makers should analyse the evident factors and finding of another nation and cross-sectional interdependence while designing clean and green advancing techniques to gain sustainable economic goals. For that reason, findings may be beneficial in impactful policy design. The economy has shown positive and inverse carbon emissions reduction with renewables. By identifying the importance of designing varying and supportive consumption practices, renewable energy can deal effectively with environmental concerns. In short, the government can facilitate low-cost renewable resources at the domestic level through budget allocation for minimising tariffs and boosting research and development in this sector. The elevation of renewable energy after a usage period has shown a negative tendency of increased and higher emission levels, contrary to its lower emission level at continuous usage. Thus, the increasing level is more advanced than reducing carbon emissions through green energy usage. Governments should focus on eliminating the negative impact of renewable energy consumption.
3. Preservation of natural resources and diminishing carbon emissions requires high-tech-eco-innovation through the assistance of domestic governments by allocating budgets to Research and Development policies enhancing eco-friendly financial development. Developing industrial nations are compelled financially to upgrade their production sector completely. To reduce monetary compulsions, boosting and maintaining technological measures with research and development is required. Relevant companies and industries can supplant conventional instruments with contemporary recyclable technology by allocating favourable credit to South Asian countries. An economic and financial sector can play a positive role and become a necessary device for sustainable growth in South Asian countries by assigning funds to generous industries, government-led clean programs, regulating eco-enemy techniques and projects, and financial burdens like taxes and penalties. By recognising the real environmental threat under certain policies, facilitating green finance, and altering financial and development strategies to minimise the threat, Multi Development Partners can play a crucial role in policy designing while deploying funds from the private sector. Good governance, clear strategies, eliminating corruption, honest policymakers, and accurate national and international environmental laws in South Asian states is essential to attain desirable targets for a sustainable environment.

This study has certain obvious constraints, some of which have been mentioned here. Firstly, more countries can be explored and offer a comparative analysis to understand the marginal impact of financial development, financial growth, and renewable energy on environmental pollution. Second, other drivers of carbon emissions can be discovered, such as environmental policy stringency, monetary and fiscal policies, R&D, human development, and green finance/investment. Lastly, non-linear models can be employed to integrate asymmetric association between variables.

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