Economic Research-Ekonomska Istraživanja

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rero20

The non-linearity between financial development and carbon footprints: the environmental roles of technological innovation, renewable energy, and foreign direct investment

Yanlei Sun, Raad Mahmoud Al-Tal, Abu Bakkar Siddik, Samiha Khan, Muntasir Murshed & Rafael Alvarado

To cite this article: Yanlei Sun, Raad Mahmoud Al-Tal, Abu Bakkar Siddik, Samiha Khan, Muntasir Murshed & Rafael Alvarado (2023) The non-linearity between financial development and carbon footprints: the environmental roles of technological innovation, renewable energy, and foreign direct investment, Economic Research-Ekonomska Istraživanja, 36:2, 2174153, DOI: 10.1080/1331677X.2023.2174153

To link to this article: https://doi.org/10.1080/1331677X.2023.2174153

Published online: 10 Mar 2023.

ECONOMIC RESEARCH-EKONOMSKA ISTRAŽIVANJA
2023, VOL. 36, NO. 2, 2174153
https://doi.org/10.1080/1331677X.2023.2174153

The non-linearity between financial development and carbon footprints: the environmental roles of technological innovation, renewable energy, and foreign direct investment

Yanlei Sun[a], Raad Mahmoud Al-Tal[b], Abu Bakkar Siddik[c], Samiha Khan[d], Muntasir Murshed[d,e] and Rafael Alvarado[f]

[a]School of Economics and Management, Shaanxi University of Science & Technology (SUST), Xi'an, Shaanxi, China; [b]Department of Economics, School of Business, University of Jordan, Amman, Jordan; [c]School of Management, University of Science and Technology of China, Hefei, China; [d]School of Business and Economics, North South University, Dhaka, Bangladesh; [e]Department of Journalism, Media and Communications, Daffodil International University, Dhaka, Bangladesh; [f]Esai Business School, Universidad Espíritu Santo, Samborondon, Ecuador

ABSTRACT
The economies of the majority of the South Asian countries have substantially expanded in the last couple of decades. Nevertheless, the simultaneous deterioration in environmental quality questions the quality of such growth performances of the South Asian countries in light of their environmental sustainability objectives. As a result, limiting the environmental hardships faced by these countries is deemed as an important agenda of the concerned governments. Therefore, this study aims to examine the determinants of carbon footprints in selected South Asian countries using advanced panel data econometric methods. Overall, the findings confirm an inverted U-shaped association between financial development and carbon footprints based on which the environmental Kuznets curve hypothesis is verified in the long run. Besides, technological innovation is evidenced to curb the short- and long run levels of carbon footprints while renewable energy transition exerts carbon footprint-inhibiting impact only in the long run. Further, the findings verify the pollution haven hypothesis by confirming carbon footprint-boosting impact of net foreign direct investment inflows. Consequently, for improving environmental quality, South Asian economies should develop their financial sectors further, discover green technologies, undergo renewable energy transition, and restrict inflows of unclean foreign direct investments.

ARTICLE HISTORY
Received 28 September 2022
Accepted 23 January 2023

KEYWORDS
Financial development; technological innovation; FDI; CS-ARDL; CO_2 emissions; renewable energy transition

JEL CODES
F64; O44; Q2; Q55; R11

CONTACT Samiha Khan samiha.khan01@northsouth.edu

1. Introduction

South Asia comprises several developing economies that have significantly flourished in the preceding decades (Usman et al., 2021). Consequently, several South Asian countries are categorized as rapidly emerging global economies. Notably, the Goldman Sachs in 2001 enlisted India, the largest South Asian nation, as one of the members of the BRIC (abbreviating for Brazil, Russia, India, and China), claiming these four emerging nations to dominate the world economy by 2050 (S. Khan et al., 2022; Li et al., 2022). Later on, in 2005, Goldman Sachs listed Bangladesh and Pakistan as of the Next Eleven countries (Qin et al., 2021) which are assumed to substantially contribute to the global economy as the successors of the BRIC. Although the economies of Sri Lanka and Nepal are not as large as the other three leading South Asian countries, these two nations are integral parts of the global tourism industry (Mehmood et al., 2021). It is noteworthy mentioning that in the last decade, the economies of the South Asian countries, as a whole, have expanded on average at a rate of around 5.32% (World Bank, 2022). Hence, it is apparent that South Asia has been an economically productive region that is fast-emerging to persistently boost the global output level.

However, concerns remain over the quality of economic growth across South Asia as several of the South Asian countries also find themselves on the list of highly-polluted global economies. Precisely, in 2020, India was positioned third while Pakistan and Bangladesh were ranked twenty-seventh and thirty-seventh, respectively, among the top emitters of Carbon dioxide (CO_2) across the world (Global Carbon Atlas, 2022). More alarmingly, despite these economies ratifying the Paris Agreement and committing to control their greenhouse gas discharges, the annual CO_2 emission levels of all South Asian countries have on average surged, year-on-year, in the 21st century (World Bank, 2022). Consequently, it can be assumed that the growths of the South Asia economies have not been environmentally sustainable as economic expansion within this region was accompanied by severe environmental distresses. Moreover, it is also admitted that South Asia is one of the most vulnerable global regions in respect of combating chronic climate change-related problems such as sea-level rise, high temperature levels, and weather extremities (Aryal et al., 2020; Naveendrakumar et al., 2019). Consequently, it has been estimated that more than 62 million people across South Asia are at risk of being forcibly displaced due to climate change adversities by 2050 (Action Aid, 2020). Thus, improving environmental quality is considered critically important for South Asian nations.

Several macroeconomic factors can be linked with the greening the growth of the South Asian economies. Ideally, these factors should expedite economic growth while controlling environmental pollution to ultimately promote low-carbon growth. Financial development can be thought of as one such factor. This is because the role of financial development in sustaining economic growth across South Asia has been duly acknowledged in preceding studies (Sophastienphong & Kulathunga, 2010). However, the low incidence of financial inclusion within this region reflects the underdeveloped state of the South Asian financial sectors. Hence, developing the financial sectors in South Asia is believed to be crucial in amplifying the economic growth rates of the South Asian economies. Although the financial sectors role in respect of promoting higher economic growth in South Asia is quite straight forward, the environmental effects associated with financial development can be uncertain. For instance, it is often argued that financing modern projects aimed at utilizing clean inputs for output production can help to address environmental concerns by limiting CO_2 emissions (Zahoor et al., 2022). In contrast, the financial sector can also be linked with environmental distresses if funding is provided for pollution-intensive projects (Abro et al., 2022). Thus, the future financial development policies in South Asia context should integrate the issue of environmental well-being so that the financial sectors in this region are not held responsible for triggering environmental distresses, especially those associated with greenhouse gas emissions.

Therefore, from the point of view of tackling the greenhouse gas emission-related environmental problems experienced in South Asia, it is relevant to check whether developing the financial sector can facilitate the utmost important goal of establishing environmental sustainability in this region. Against this backdrop, this study aims to evaluate the environmental repercussions associated with financial development in leading South Asian economies (India, Sri Lanka, Nepal, Pakistan, and Bangladesh) considering the timeframe between 2000 and 2018. In addition, the influences of technological innovation, renewable energy, and Foreign Direct Investments (FDI) on environmental quality in South Asia are also explored. Overall, this study is expected to aid in formulating policies that can enable these nations to comply with the environment-related promises they made by signing various international environmental pacts such as the 'Paris Agreement and the 2030 Sustainable Development Goals (SDG)'. Besides, the conclusions drawn from this study's findings can further help the selected South Asian countries in designing blueprints for achieving carbon neutrality in the future.

In terms of contributions, this study tests the validity of the Environmental Kuznets Curve (EKC) hypothesis using unconventional proxy variables for economic growth and environmental quality. Precisely, since the extant literature is saturated with studies that have used the national income level and CO_2 emissions for quantifying economic growth and environmental quality, respectively, this study uses South Asian financial development and carbon footprint data instead. Besides, it is worth mentioning that the previous studies have largely assessed the linear environmental impacts of financial development but have not emphasized the potential non-linear associations among these variables. However, for designing long-term financial development policies for ensuring environmental sustainability, scrutinizing this possible non-linearity can be deemed important. On the other hand, the use of carbon footprints data as an alternative for CO_2 emissions is relevant because carbon footprints not only account for the CO_2 emissions but also consider the issue of carbon sequestration (Fan et al., 2022), especially by measuring the environmental impact 'in terms of the volume of ecologically productive land required for generating CO_2 emissions and simultaneously absorbing them'.[1] Notably, the preceding studies have not extensively checked whether the carbon footprint-related EKC hypothesis is valid for South Asian economies.

In the next section, the literature review is presented to discuss the theoretical framework and the existing empirical findings relevant to this study. The methodology is then discussed in the next section for introducing the analytical models used and outlining the estimation approach followed. Subsequently, the findings are reported while the last section provides the concluding remarks along with policy suggestions.

2. Literature review

2.1. Theoretical framework

In general, many factors can be related to the deterioration of environmental conditions worldwide. Theoretically, Grossman and Krueger (1991, 1995) introduced the 'Environmental Kuznets Curve (EKC) hypothesis' and claimed that economic activities are initially likely to be pollution-intensive but pollution-inhibiting later on whereby the EKC is expected to portray an inverse U-shape (Agozie et al., 2022; Bilgili et al., 2022). This hypothesis links the economy with the environment by assuming that in the preliminary phases of growth, developing nations are more interested in expediting economic expansion by employing pollution-intensive factors of production. These adverse environmental effects are believed to be driven by the scale and composition effects of economic growth (Jahanger et al., 2022b; Murshed et al., 2021a). Nonetheless, once a decent degree of growth is achieved, these nations are likely to be more conscious about environmental devastations whereby pollution-intensive factors of production may be replaced with cleaner factors. These favorable environmental impacts are said to be stimulated by the technique effect of economic growth (Beyene, 2022).

Accordingly, several existing studies have aimed to verify the non-linear inverted U-shaped nexus between economic growth and different indicators of environmental quality. However, these studies have largely assessed environmental consequences associated with a rise in the national income level (Pata et al., 2022). Though a country's national income level is an appropriate indicator of its economic growth level, using this variable to test the EKC hypothesis overlooks the effects of economic growth-facilitating factors on environmental well-being. In this regard, it is relevant to check how the factors that determine the growth of an economy influence the quality of the environment because it is expected to help in designing policies that can be useful in both amplifying economic growth rate and inhibiting environmental degradation. Financial development is one such economic growth-facilitating macroeconomic factor that induces environmental consequences as well. For instance, since economic output production requires capital investment, it is ideal for the financial sector to be sufficiently developed so that it can supply adequate funds for financing private projects (Shahbaz et al., 2022). Although financial development is almost certain to promote economic growth, its consequences on environmental well-being are ambiguous. This is because financing pollution-intensive projects can worsen environmental quality (Ahmad et al., 2022) while investing funds in clean projects can lead to better environmental outcomes (Usman et al., 2022). Under such circumstances, testing the financial development-related EKC hypothesis has critical policy implications, especially in respect of making sure that the financial sector generates economic and environmental benefits in tandem.

Another conventionally used theoretical argument for understanding the environmental quality determinants is the 'Pollution Haven Hypothesis (PHH)'. This theory presumes that FDI flowing into developing countries, in particular, are likely to turn these nations into pollution havens for foreign investors and thereby induce large-scale production of pollution-intensive output (Wang & Luo, 2022). This is because in developed countries strict environmental laws do not allow dirty industries to grow whereby there is always a tendency to outsource the production of pollution-intensive commodities from developing countries that are yet to enact strong environmental regulations (Apergis et al., 2022). Consequently, in this scenario, incoming FDI can be assumed to induce environmental hardships for the FDI-recipient developing nations whereby their financial globalization policies can be questioned for deteriorating environmental quality. Contrastingly, many studies have argued that FDI influx comes with relevant technologies that can help in cleaning economic output production-related activities whereby favorable environmental consequences can be expected from financial globalization (Z. Chen et al., 2022; Nejati & Taleghani, 2022). Accordingly, the 'Pollution Halo Effect (PHE) hypothesis' was introduced which advocates that FDI can be a credible means for addressing environmental concerns related to surging discharges of greenhouse gases (Zheng et al., 2022).

Apart from financial development and FDI inflows, changes in environmental conditions are said to be triggered by other vital factors such as technological innovation and energy use. Firstly, modern technologies are preconceived to make resource utilization more efficient so that the associated environmental adversities can be internalized and limited. Secondly, the energy sector is said to be the leading contributor to greenhouse gas emission-related environmental hardships as most energy sectors worldwide are predominantly fossil fuel-dependent (Kartal et al., 2022). Consequently, often withdrawal from fossil fuel (unclean energy) employment and adoption of renewable energy (clean energy) are recommended as effective means of tackling adverse environmental concerns (Afshan et al., 2022; Jahanger et al., 2022a). Furthermore, the environmental impacts of technological innovation and renewable energy are also assumed to be interlinked as technological advancement can be expected to facilitate the 'transition from the use of non-renewable to renewable energy' which, in turn, can substantially reduce greenhouse gas emission levels.

2.2. Empirical evidence in extant literature

The literature related to the EKC hypothesis mostly documents studies exploring the national income-CO_2 emissions nexus. In this regard, using data from 1972 to 2019, Sadiq et al. (2022) remarked that the EKC hypothesis exists in the cases of selected South Asian economies and also mentioned that scaling non-renewable energy consumption and being more globalized boost CO_2 emissions in these countries. Similarly, M. B. Khan et al. (2022) documented evidence regarding the 'inverted U-shaped nexus' between national income level and CO_2 emissions in South Asia. Moreover, among the existing studies on individual South Asian countries, X. Chen et al. (2022) used data from Bangladesh and found that the EKC hypothesis is valid, financial development curbs CO_2 emissions, and energy consumption boosts CO_2

emissions. Besides, the authors also argued that financial development jointly with energy use and economic growth boosts and inhibits Bangladesh's CO_2 emission levels, respectively. On the other hand, Itoo and Ali (2022) invalidated the EKC hypothesis for India. Similarly, the findings from the study by Hossain et al. (2023) defied the validity of the CO_2 emission-related EKC hypothesis in India.

Shakoor et al. (2022) used data from Pakistan and argued that the CO_2 emissions-related EKC hypothesis holds in the long run while in the short run the national income-CO_2 emissions nexus is U-shaped. Additionally, the authors said that Pakistan can curb its CO_2 emission figures by scaling renewable energy consumption in the long-run. In another related study on six South Asian countries, Murshed et al. (2021b) remarked that the EKC hypothesis does not homogeneously hold for all South Asian countries. Precisely, the authors claimed that the CO_2 emission-related EKC hypothesis is valid for Sri Lanka, Bangladesh, India, and Nepal but not for Pakistan and Bhutan. The authors further added that although the EKC-related findings are heterogeneous across the South Asian countries, FDI inflows homogeneously degrade environmental quality in these countries by boosting their CO_2 emissions. Consequently, the PHH was verified for the concerned South Asian nations.

Much like the cases of the South Asian nations, mixed results concerning the CO_2 emissions- and national income-related EKC hypothesis can be observed for non-South Asian countries. Li and Haneklaus (2022) verified the inverted U-shaped impacts of national income growth on CO_2 emission levels of Group of Seven (G7) countries. Additionally, the authors concluded that clean energy consumption and urbanization decrease CO_2 emissions both in the short and long run. In the context of six members of the 'Association of Southeast Asian Nations (ASEAN)', Pata et al. (2022) argued that since higher national income boosts emissions of CO_2 in the short but reduces emissions in the long run, the EKC hypothesis can be deemed valid. Further, the authors recorded evidence regarding FDI inflows, international trade, and international tourism boosting CO_2 emissions in the long-run while renewable energy was seen to curtail the short-run CO_2 emission figures. Similarly, employing data from Mexico, Indonesia, Turkey, and Nigeria and using quantile regression analysis, Du et al. (2022) recorded evidence that the EKC hypothesis is valid across all emission quantiles. Further, the authors concluded that FDI inflows and renewable energy use boost and inhibit consumption-based CO_2 emissions, respectively.

Amidst the rich literature on CO_2 emissions-related EKC hypothesis, a limited number of studies have tested the authenticity of the EKC hypothesis using carbon footprint data. Elshimy and El-Aasar (2020) utilized data from Arab states and concluded that the carbon footprint-related EKC hypothesis is valid. In addition, the authors mentioned that renewable electricity use helps in curbing carbon emissions while scaling non-renewable electricity consumption boosts emissions in the long run. In the context of Malaysia, Bello et al. (2018) confirmed the carbon footprint-related EKC hypothesis for the period 1991–2014 but not for the period 1971–1990. In contrast, the authors mentioned that higher hydroelectricity consumption contributes to lowering Malaysia's carbon footprint figures during the period 1971–1990 but not during the period 1991–2014. Regarding the Sultanate of Oman, Alam et al. (2022) confirmed the authenticity of the carbon footprint-related EKC hypothesis.

Moreover, the authors concluded that the development of the financial sector and more use of low-carbon energy respectively boost and reduce Oman's carbon footprint levels both in the short- and long run. Likewise, Wang (2021) documented statistical evidence regarding financial development positively influencing carbon footprint levels in 'BRICS (Brazil, Russia, India, China, and South Arica)'. However, for the cases of selected countries under the 'Belt and Road Initiative (BRI)', Hafeez et al. (2019) concluded that financial development is effective in curbing carbon footprints. Besides, the authors mentioned that FDI inflows can also be helpful in promoting environmental development by reducing the carbon footprint figures of the selected BRI nations whereby the PHH can be validated.

3. Methodology

3.1. Empirical model

According to this study's objectives, two empirical models are considered in which the validities of the EKC hypothesis and PHH are tested by expressing carbon footprints as functions of financial development, technological innovation, renewable energy use, and foreign direct investments. These models are shown as:

$$\textbf{Model A}: \ \ln CF_{i,t} = \delta_0 + \delta_1 FD_{i,t} + \delta_2 (FD_{i,t})^2 + \delta_3 \ln TI_{i,t} + \delta_4 FDI_{i,t} + \varepsilon_t \quad (1)$$

$$\textbf{Model B}: \ \ln CF_{i,t} = \delta_0 + \delta_1 FD_{i,t} + \delta_2 (FD_{i,t})^2 + \delta_3 RES_{i,t} + \delta_4 FDI_{i,t} + \varepsilon_t \quad (2)$$

In both models, i and t respectively denote cross-sectional units and study period, ε denotes the error term, δ_0 is the intercept parameter, and δ_1, δ_2, δ_3, ... and δ_4 denote the parameters that capture the elasticities of carbon footprints to one unit positive change in the explanatory variables of concern. The prefix ln indicates the natural log transformation of the respective variable which is done to make sure that the predicted coefficients are elasticity parameters concerning the dependent variable. The dependent variable lnCF stands for the annual consumption-based per capita carbon footprint figures of the selected South Asian nations. Since a rise in the carbon footprint level is synonymous with a decline in the quality of the environment (Elshimy & El-Aasar, 2020), positive (negative) signs of the elasticity parameters would indicate an environmental degradation (improvement) effect. The dependent variable FD stands for financial development which is proxied by the extent of private sector borrowings across the South Asian countries. Accordingly, in the extant literature, higher (lower) private sector borrowings have been considered as a rise (fall) in the level of financial development (X. Chen et al., 2022). Besides, in line with the EKC theory, the squared term of the financial development variable (i.e., FD^2) is included in both models. For the EKC hypothesis to hold, the elasticity parameters concerning FD and FD^2 must be positive and negative, respectively (i.e., $\delta_1 > 0$ and $\delta_2 < 0$).

In Model A, the dependent variable lnTI stands for the technological innovation which is captured in terms of the annual level of technical cooperation grants provided to the respective South Asian nations. Since more grants can be expected to facilitate investment in research and development purposes, a rise in the value of this variable can be interpreted as technological innovation and vice-versa (Zafar et al., 2021). In Model B, the variable RES stands for the 'share of renewables in the annual energy consumption profiles of the South Asian countries'. A rise (fall) in this share has been acknowledged as a fall (rise) in fossil fuel dependency (Xue et al., 2021); thus, its inclusion in the model is expected to provide key insights regarding how environmental quality in South Asia responds to a fall in the fossil fuel dependency within the South Asian economies. The variables lnTI and RES are included in separate models to avoid multicollinearity concerns stemming from a potential correlation between these variables. This is because it has been acknowledged in the literature that the development of the latest technologies is a prerequisite for making a transition from the use of non-renewable to renewable energy (Geng & Ji, 2016). Lastly, the variable FDI stands for the annual influx of FDI into the South Asian economies; this variable is included to test the authenticity of the PHH. As per the theoretical arguments, the PHH is valid only if the associated elasticity parameter is positive (i.e., $\delta_4 > 0$) and invalid otherwise (Hafeez et al., 2019).

3.2. Data

Based on availability, data from five leading South Asian nations for the period from 2000 to 2018 are considered. The variable lnCF is quantified as global hectares of biologically productive land per capita; FD is measured as the share of private sector credits in the GDP; lnTI is measured in current US$; RES is measured as the share of renewables in total final energy consumption level; FDI is measured as the share of the net influx of FDI in the GDP. The data concerning lnCF are acquired from Global Footprint Network (2022) while that of the rest of the variables are retrieved from World Bank (2022). The descriptive statistics and pair-wise correlation matrix are displayed in Tables 1 and 2, respectively. Besides, the findings from the variance inflation factor analysis, presented in Table 3, nullify the possibility of multicollinearity concerns in either of the model. This is because neither the individual scores are above 5 nor are the tolerance scores below 0.2.

3.2. Estimation strategy

The estimation strategy spans several stages. In the first stage, Pesaran's (2021) and Breusch and Pagan (1980) tests are employed for conducting the cross-sectional

Table 1. Descriptive statistics.

Descriptives	lnCF	FD	lnTI	RES	FDI
Minimum	−2.2613	14.5791	17.7931	26.8800	−0.0984
Median	−1.0968	33.8182	19.0367	49.3300	0.9604
Maximum	−0.4199	76.1690	20.0207	91.3100	3.6683
Mean	−1.2349	35.9628	18.9180	54.9256	1.0467
Std. Dev.	0.5234	13.1057	0.5487	18.1655	0.7734
Skewness	−0.5105	0.5568	−0.1024	0.7563	1.1664
Kurtosis	2.2087	2.9008	2.0650	2.4948	2.7399
Obvs.	95	95	95	95	95

Source: Authors' computation.

Table 2. Correlation matrix.

Correlation	lnCF	FD	lnTI	RES	FDI
lnCF	1.0000				
FD	0.9081***	1.0000			
lnTI	0.1335	0.0400	1.0000		
REC	−0.6443***	0.0923	−0.5467***	1.0000	
FDI	0.6506***	0.1357	0.2343**	−0.5556*	1.0000

Note: *** and ** respectively denote statistical significance at 1% and 5%, respectively.
Source: Authors' computation.

Table 3. Results from variance inflation factor analysis.

Model	Variable	VIF	Tolerance	Model	Variable	VIF	Tolerance
A	FDI	1.0800	0.9291	**B**	FDI	1.5200	0.6560
A	lnTI	1.0600	0.9450	**B**	REC	1.5100	0.6626
A	FD	1.0200	0.9815	**B**	FD	1.0600	0.9409
A	Mean	1.0500		**B**	Mean	1.3700	

Source: Authors' computation.

Table 4. Cross-sectional dependency test results.

	Pesaran's (2021) CD test		Breusch and Pagan (1980) LM test	
Variable	Test Statistic	Probability	Test Statistic	Probability
lnCF	5.0150***	0.0000	45.6530***	0.0000
FD	−1.3880	0.1811	24.6840***	0.0060
lnTI	1.5850	0.1130	10.2510	0.4188
RES	4.5410***	0.0000	65.1950***	0.0000
FDI	1.7160*	0.0861	37.3080***	0.0000

Notes: Statistical significance confirms cross-sectional dependence.
*** and * respectively denote statistical significance at 1% and 10%, respectively.
Source: Authors' computation.

dependency analysis. Both these tests predict test statistics for each variable assuming no cross-sectional dependency as the null hypothesis. In the second stage, the slope heterogeneity-related problem is evaluated using Blomquist and Westerlund (2013) method. This technique predicts two test statistics for each model assuming homogeneous slope coefficients as the null hypothesis. The findings from the cross-sectional dependency analysis, as shown in Table 4, confirms the issue. On the other hand, Table 5 verifies the slope heterogeneity-related problems in the data. Since these two-panel data-related problems are evidenced, the subsequent stages of the estimation strategy include methods that can 'handle cross-sectionally-dependent heterogeneous panel data'.

In the third stage, the respective integration order of the variables is detected by conducting 'Pesaran's (2007) Cross-sectionally adjusted Augmented Dickey-Fuller (CADF) and Cross-sectionally adjusted Im-Pesaran-Shin (CIPS)' unit root tests. Both these tests predict test statistics for each variable assuming 'non-stationarity of the concerned series' as the null hypothesis. In the fourth stage, Westerlund's (2007) method is employed for checking the possible cointegrating associations among the variables in the respective model. This method tackles the cross-sectional dependency issue by considering bootstrapped replications and predicts four test statistics, for each model, considering no cointegration among the concerned variables as the null hypothesis. In stage 5, the Chudik et al. (2013) Cross-section augmented-

Autoregressive Distributed Lag (CS-ARDL) regression estimator is used to calculate the carbon footprints elasticities. This technique is efficient in dealing with (a) cross-sectionally-dependent heterogeneous panel data, (b) mixed integration order of the variables up to the first difference, and (c) endogenous covariates. Further, for robustness checks of the CS-ARDL elasticity estimates, especially for the long-run scenario, 'Eberhardt and Teal's (2010) Augmented Mean Group (AMG) panel regression estimator', which also accounts for identified panel data problems, is employed for re-estimating the models. Finally, in the last stage, Dumitrescu and Hurlin (2012) causality estimator is used to determine the causal relationships. This technique predicts test statistics considering the 'independent variable Granger causing the dependent variable as the null hypothesis'.

4. Empirical results

Firstly, in Table 6, the unit root test results are reported. It is evident from the outcomes concerning the CADF test that all variables have a common integration order at I(1) which means that the variables become stationary at the first difference. However, the outcomes concerning the CIPS test do not corroborate the CADF test's outcomes. In this regard, the CIPS test suggests that the integration order of the variables is mixed since the variable lnTI has an integration order of I(0) which implies that this particular variable becomes stationary at the level. Hence, overall, we can claim that the integration orders of the concerned variables are mixed with combinations of level and first difference. Secondly, the cointegration test's outcomes, shown in Table 7, confirm cointegration among the variables in each of the two models. Consequently, for the selected South Asian economies, we can claim that there are

Table 5. Slope heterogeneity test results.

	Blomquist and Westerlund (2013) test		
Model	Specification	Delta stat.	Adjusted Delta stat.
A	$\ln CF = \int(FD, FD^2, \ln TI, FDI)$	3.0240***	3.5650***
B	$\ln CF = \int(FD, FD^2, RES, FDI)$	3.1491***	3.8221***

Notes: Statistical significance confirms heterogeneous slope coefficients.
***Denotes statistical significance at 1%.
Source: Authors' computation.

Table 6. Unit root test results.

	Pesaran's (2007) CADF test		Pesaran's (2007) CIPS test	
Variable	Test statistic	Probability	Test statistic	Critical value
lnCF	−0.6020	1.0000	−2.3930	−2.7400 (10%)
ΔlnCF	−5.3630***	0.0000	−5.2570***	−3.1500 (1%)
FD	−2.3800	0.9800	−1.4400	−2.7400 (10%)
ΔFD	−3.9920***	0.0000	−3.9920***	−3.1500 (1%)
lnTI	−1.3660	0.9220	−2.8010*	−2.7400 (10%)
ΔlnTI	−4.8060***	0.0000	−4.7790***	−3.1500 (1%)
RES	−2.3180	0.4660	−2.0030	−2.7400 (10%)
ΔRES	−4.0750***	0.0000	−4.0750***	−3.1500 (1%)
FDI	−1.7660	0.8720	−2.3140	−2.7400 (10%)
ΔFDI	−4.1600***	0.0000	−4.1600***	−3.1500 (1%)

Notes: Δ denotes first difference; Statistical significance confirms stationarity of the series.
***and * respectively denote statistical significance at 1% and 10%.
Source: Authors' computation.

Table 7. Cointegration test results.

		Westerlund (2007) test			
Model	Statistic	Value	Z-value	Prob.	Prob. (Robust)
A	Gt	−2.4020	1.1380	0.8720	0.4800
	Ga	−1.9070***	3.9980	1.0000	0.0000
	Pt	−4.5260	1.3510	0.9120	0.2400
	Pa	−2.2020**	3.3050	0.9990	0.0400
B	Gt	−3.5850**	−2.2610	0.0120	0.0400
	Ga	−7.9770**	2.1010	0.9820	0.0400
	Pt	−8.3540*	−3.0230	0.0010	0.0800
	Pa	−9.9890	0.6660	0.7470	0.1200

Notes: Statistical significance confirms cointegration among the model's variables; Bootstrapped replications = 5000.
***, **, and * respectively denote statistical significance at 1%, 5%, and 10%.
Source: Authors' computation.

Table 8. Results from CS-ARDL analysis.

	Model A		Model B	
Regressor	Short-run	Long-run	Short-run	Long-run
FD	0.0422	0.0695**	0.0449	0.0710**
	(0.0440)	(0.0344)	(0.0407)	(0.0354)
FD^2	−0.0008	−0.0006**	−0.0009*	−0.0007***
	(0.0007)	(0.0003)	(0.0005)	(0.0003)
lnTI	−0.1720**	−0.2040**	–	–
	(0.0805)	(0.1019)		
RES	–	–	0.0021	−0.0056***
			(0.0018)	(0.0017)
FDI	0.0616*	0.0473**	0.0641**	0.0454***
	(0.0313)	(0.0232)	(0.0320)	(0.0183)
ECT(-1)	−0.3690***		−0.4040***	
	(0.1480)		(0.1300)	
Adj. R-sq.	0.501		0.490	

Notes: ECT(-1) denotes one period-lagged error-correction term; standard errors are presented within parentheses.
***, **, and * respectively denote statistical significance at 1%, 5%, and 10%.
Source: Authors' computation.

long-run associations among the carbon footprint, financial development, technological innovation, renewable energy use, and FDI influx levels.

Table 8 displays the short- and long-run elasticities of carbon footprints that are derived using the CS-ARDL estimator. First, the estimates concerning both models show that only for the long-run scenario, financial development initially boosts per capita carbon footprint levels but afterward, as the financial sectors of the South Asian nations are developed by a certain amount (i.e., the threshold financial development level) further financial development accounts for lower carbon footprints. This claim is duly supported by the positive and negative signs of the statistically significant estimated elasticity parameters related to the variable FD and its squared term, respectively. Hence, the long-run findings verify the inverted U-shaped relationship between financial development and carbon footprints whereby the EKC hypothesis can be deemed valid. Moreover, considering these long-run estimates, the threshold share of private sector borrowings in the GDP of the selected South Asian nations is estimated at around 58-60% which is substantially higher than the average shares (around 47%) in 2018. Therefore, it is evident that the financial sectors in South Asian countries are yet to be sufficiently developed and whereby their financial developments policies are not aligned with their environmental sustainability objectives.

Among the other key findings, the estimates concerning Model A reveal that technological innovation promotes environmental sustainability. Precisely, the associated results confirm that a 1% rise in the annual share of technical grants in the GDP of the concerned South Asian nations declines the per capita carbon footprint levels by 0.17% in the short run and 0.20% in the long run. Thus, the role of technological development in controlling atmospheric pollution in South Asia is highlighted by these findings. In this regard, it can be assumed that the latest technologies can improve the efficiency rate at which natural resource is consumed whereby the environmental adversities associated with natural resource use can be effectively contained. For instance, new technologies can make productive utilization of energy resources which, in turn, can help limit atmospheric discharge of CO_2 in South Asia. Similarly, Cheng et al. (2021) concluded that technological innovation in selected members of the Organization for Economic Cooperation and Development not only inhibits CO_2 emissions directly but also indirectly neutralizes the CO_2 emission-boosting impacts associated with economic growth.

On the other hand, the estimates concerning Model B confirm that making the national energy portfolios less fossil fuel-intensive can help address the environmental concerns of the South Asian countries, but only in the long run. Notably, it is evidenced that a 1% rise in the average annual share of renewables in the final energy consumption profiles of the selected South Asian countries can reduce carbon footprint by 0.01%. This long-run finding highlights that reducing the extent of fossil fuel dependency within the energy systems of the South Asian nations can limit the energy-use-led atmospheric discharges of CO_2 whereby the carbon footprint levels of these countries can be effectively reduced. However, a similar carbon footprint-influencing impact of the renewable energy transition could not be confirmed for the short-run scenario which could be because the largely underdeveloped renewable energy sectors in South Asia are still passing their juvenile periods. Consequently, in the short-run, a small rise in the renewable energy share is justifiably not effective in curbing carbon footprints. The long-run findings corroborate the conclusions put forward by Bello et al. (2018) and Alam et al. (2022) for Malaysia and Oman, respectively. In those studies, the authors argued that scaling employment of relatively clean energy resources can help in addressing environmental concerns by curbing the carbon footprint figures in these countries.

Lastly, for both models, the estimates shown in Table 8 confirm the environment-degrading effect of FDI flowing into South Asia. Precisely, a 1% rise in the annual share of net FDI influx in the GDP of the concerned South Asian countries is estimated to boost carbon footprints by 0.06% in the short run and 0.05% in the long run. Although the marginal effects are comparatively lower in the long run, the fact that more incoming FDI leads to higher carbon footprints gives the impression that South Asian countries are considered pollution havens by foreign investors. Therefore, these findings verify the PHH for the selected South Asian countries. Hafeez et al. (2019) also recorded statistical finding regarding FDI influx positively influencing carbon footprint levels in BRI countries. Similarly, Murshed et al. (2021b) verified the PHH for South Asian nations by documenting statistical evidence that higher FDI inflows

Table 9. Robustness test results.

	Model A		Model B	
Regressor	Coefficient	Probability	Coefficient	Probability
FD	0.0184*	0.0010	0.0113*	0.0065
FD^2	−0.0002*	0.0001	−0.0005*	0.0002
lnTI	−0.0101**	0.0049	–	–
RES	–	–	−0.0082***	0.0014
FDI	0.0890**	0.0444	0.0798**	0.0370

Notes: ***, **, and * respectively denote statistical significance at 1%, 5%, and 10%.
Source: Authors' computation.

Table 10. Causality test results.

Dumitrescu and Hurlin (2012) test

Null Hypo.	W-bar stat.	Z-bar statistic	Z-bar tilde statistic
FD ≠ lnCF	12.4488	6.6793* (0.1000)	1.6994 (1.000)
lnCF ≠ FD	4.1759	2.4327 (0.7000)	1.3510 (0.7000)
lnTI ≠ lnCF	16.7917	10.1129* (0.1000)	2.8439* (0.1000)
lnCF ≠ lnTI	1.1048	0.1657 (1.000)	−0.0596 (0.9000)
RES ≠ lnCF	4.9019	3.2445 (0.3000)	1.9033 (0.3000)
lnCF ≠ RES	7.0784	2.4337 (0.4000)	0.2842 (0.7000)
FDI ≠ lnCF	2.9049	1.0117 (0.4000)	0.3811 (0.9000)
lnCF ≠ FDI	1.8589	−0.1587 (0.9000)	−0.4117 (0.6000)

Notes: '≠ implies does not Granger cause; Statistical significance confirms rejection of the null hypothesis; Bootstrapped replications = 5000; probability values are presented within parentheses; * denotes statistical significance at 1%'.
Source: Authors' computation.

positively impact CO_2 emission levels within South Asia. A similar finding for the cases of selected ASEAN states was documented by Pata et al. (2022), as well.

Moreover, from Table 8, it is observed that the predicted parameters concerning the error correction terms for both models are negative and statistically significant. Precisely, these estimates affirm disequilibrium to equilibrium correction speeds of around 37% for Model A and 40% for Model B. Furthermore, Table 9 displays the carbon footprint elasticities derived from the robustness analysis using the AMG estimator. Comparing the findings displayed in Tables 8 and 9, it can be claimed that the findings are robust across alternative estimation methods in terms of the signs of the predicted elasticity parameters.

Finally, the outcomes from the causality analysis, as displayed in Table 10, confirm unidirectional causal relationships running from financial development and technological innovation to carbon footprints. Hence, these findings support the corresponding regression outcomes and verify the financial development-carbon footprint-related EKC hypothesis and certify the carbon footprint-reducing effect of technological innovation in the concerned South Asia economies.

5. Conclusion and policies

The majority of the developing countries in South Asia are assumed to record significant growth performances in the next couple of decades whereby it is critically important for these nations to achieve environmentally-friendly economic growth. Hence, this study aimed to identify the determinants of carbon footprints in five major South Asian economies between 2000 and 2018. In this regard, this study employed estimation techniques that are efficient in neutralizing the effects of endogeneity, slope heterogeneity, and cross-sectional dependency-related problems in the data. Overall, the findings verified the non-linear inverted U-shaped impacts of financial development on the long-run carbon footprint figures of the concerned South Asian nations. Consequently, the EKC hypothesis was deemed valid for the long run case. More importantly, the predicted threshold financial development levels were significantly higher than the average financial development level of the selected South Asian countries. Besides, for both the short- and long-run scenarios, technological innovation was found to exert carbon footprint-inhibiting effects while renewable energy transition was evidenced to curb carbon footprints only in the long run. In addition, evidence regarding the carbon footprint-reducing effect of net FDI influx validated the existence of the PHH for both the short- and long-run.

In line with these findings, the concerned governments of the South Asian countries should instruct their respective central banks to adopt financial development policies through which the share of private sector borrowings in the GDP of the South Asian nations can be substantially enhanced in the future. These policies are expected to help the South Asian nations reach the predicted threshold financial development level so that the environmental concerns faced by these countries are addressed, particularly by scaling finance for clean initiatives. Moreover, it is relevant to scale investments in technological development projects, particularly those aimed at discovering latest technologies that can develop the underdeveloped renewable energy sectors across South Asia. Given the fact that energy insecurity concerns within this region are likely to grow in the next decade or so, it is high time the South Asian countries adopt measures that can gradually transform their respective energy systems from being predominantly fossil fuel-reliant to being largely dependent on renewable resources. Furthermore, these countries should emphasize enacting laws for restricting the influx of unclean FDI.

Data constraints limited the sample of the South Asian economies considered for analysis purposes. Hence, future studies should aim at extending the country sample for conducting more regionally-representative studies. Additionally, this study can be replicated using counterfactual samples for testing the external reliability of the findings and the policy suggestions put forward.

Note

1. For an in-depth understanding of the methodology of estimating the carbon footprint level of a country, see Global Footprint Network (2022) and Tillaguango et al. (2021).

Authors' contribution

All authors contributed equally.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Shaanxi University of Science and Technology (21Y048); National College Students Innovation and Entrepreneurship Training Program (202210708036); the Projects of Shaanxi Provincial Science and Technology Department (2023CXRKK091).

ORCID

Raad Mahmoud Al-Tal http://orcid.org/0000-0002-2336-9519
Abu Bakkar Siddik http://orcid.org/0000-0002-3953-198X
Samiha Khan http://orcid.org/0000-0001-9332-0967
Muntasir Murshed http://orcid.org/0000-0001-9872-8742
Rafael Alvarado http://orcid.org/0000-0002-3213-5431

Data availability statement

Data will be made available upon request.

References

Abro, A. A., Alam, N., Murshed, M., Mahmood, H., Musah, M., & Rahman, A. K. M. (2022). Drivers of green growth in the Kingdom of Saudi Arabia: Can financial development promote environmentally sustainable economic growth? *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-23867-z

Action Aid. (2020). *Climate migration in South Asia set to treble by 2050 due to political inaction on global warming*. https://actionaid.org/news/2020/climate-migration-south-asia-set-treble-2050-due-political-inaction-global-warming

Afshan, S., Ozturk, I., & Yaqoob, T. (2022). Facilitating renewable energy transition, ecological innovations and stringent environmental policies to improve ecological sustainability: Evidence from MM-QR method. *Renewable Energy*, *196*, 151–160. https://doi.org/10.1016/j.renene.2022.06.125

Agozie, D. Q., Gyamfi, B. A., Bekun, F. V., Ozturk, I., & Taha, A. (2022). Environmental Kuznets Curve hypothesis from lens of economic complexity index for BRICS: Evidence from second generation panel analysis. *Sustainable Energy Technologies and Assessments*, *53*, 102597. https://doi.org/10.1016/j.seta.2022.102597

Ahmad, M., Ahmed, Z., Yang, X., Hussain, N., & Sinha, A. (2022). Financial development and environmental degradation: Do human capital and institutional quality make a difference? *Gondwana Research*, *105*, 299–310. https://doi.org/10.1016/j.gr.2021.09.012

Alam, N., Hashmi, N. I., Jamil, S. A., Murshed, M., Mahmood, H., & Alam, S. (2022). The marginal effects of economic growth, financial development, and low-carbon energy use on carbon footprints in Oman: Fresh evidence from autoregressive distributed lag model analysis. *Environmental Science and Pollution Research International*, *29*(50), 76432–76445. https://doi.org/10.1007/s11356-022-21211-z

Apergis, N., Pinar, M., & Unlu, E. (2022). How do foreign direct investment flows affect carbon emissions in BRICS countries? Revisiting the pollution haven hypothesis using bilateral FDI flows from OECD to BRICS countries. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-23185-4

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2020). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environment, Development and Sustainability*, *22*(6), 5045–5075. https://doi.org/10.1007/s10668-019-00414-4

Bello, M. O., Solarin, S. A., & Yen, Y. Y. (2018). The impact of electricity consumption on CO_2 emission, carbon footprint, water footprint and ecological footprint: The role of hydropower in an emerging economy. *Journal of Environmental Management*, *219*, 218–230. https://doi.org/10.1016/j.jenvman.2018.04.101

Beyene, S. D. (2022). Going beyond the traditional EKC hypothesis: A panel quantile approach. *International Journal of Environmental Studies*, *80*(1), 93–112. https://doi.org/10.1080/00207233.2022.2037327

Bilgili, F., Ozturk, I., Kocak, E., Kuskaya, S., & Cingoz, A. (2022). The nexus between access to electricity and CO_2 damage in Asian Countries: The evidence from quantile regression models. *Energy and Buildings*, *256*, 111761. https://doi.org/10.1016/j.enbuild.2021.111761

Blomquist, J., & Westerlund, J. (2013). Testing slope homogeneity in large panels with serial correlation. *Economics Letters*, *121*(3), 374–378. https://doi.org/10.1016/j.econlet.2013.09.012

Breusch, T. S., & Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. *The Review of Economic Studies*, *47*(1), 239–253. https://doi.org/10.2307/2297111

Chen, X., Rahaman, M., Hossain, M., & Chen, S. (2022). Is growth of the financial sector relevant for mitigating CO_2 emissions in Bangladesh? The moderation role of the financial sector within the EKC model. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02447-8

Chen, Z., Paudel, K. P., & Zheng, R. (2022). Pollution halo or pollution haven: Assessing the role of foreign direct investment on energy conservation and emission reduction. *Journal of Environmental Planning and Management*, *65*(2), 311–336. https://doi.org/10.1080/09640568.2021.1882965

Cheng, C., Ren, X., Dong, K., Dong, X., & Wang, Z. (2021). How does technological innovation mitigate CO_2 emissions in OECD countries? Heterogeneous analysis using panel quantile regression. *Journal of Environmental Management*, *280*, 111818.

Chudik, A., Mohaddes, K., Pesaran, M., & Raissi, M. (2013). *Debt, inflation and growth robust estimation of long-run effects in dynamic panel data models* (No. 162). Federal Reserve Bank of Dallas. https://www.dallasfed.org/~/media/documents/institute/wpapers/2013/0162.pdf

Du, L., Jiang, H., Adebayo, T. S., Awosusi, A. A., & Razzaq, A. (2022). Asymmetric effects of high-tech industry and renewable energy on consumption-based carbon emissions in MINT countries. *Renewable Energy*, *196*, 1269–1280. https://doi.org/10.1016/j.renene.2022.07.028

Dumitrescu, E. I., & Hurlin, C. (2012). Testing for granger non-causality in heterogeneous panels. *Economic Modelling*, *29*(4), 1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014

Eberhardt, M., & Teal, F. (2010). Productivity analysis in global manufacturing production. Discussion Paper 515, Department of Economics, University of Oxford. https://ora.ox.ac.uk/objects/uuid:f9d91b40-d8b7-402d-95eb-75a9cbdcd000

Elshimy, M., & El-Aasar, K. M. (2020). Carbon footprint, renewable energy, non-renewable energy, and livestock: Testing the environmental Kuznets curve hypothesis for the Arab world. *Environment, Development and Sustainability*, *22*(7), 6985–7012. https://doi.org/10.1007/s10668-019-00523-0

Fan, W., Huang, S., Yu, Y., Xu, Y., & Cheng, S. (2022). Decomposition and decoupling analysis of carbon footprint pressure in China's cities. *Journal of Cleaner Production*, *372*, 133792. https://doi.org/10.1016/j.jclepro.2022.133792

Geng, J. B., & Ji, Q. (2016). Technological innovation and renewable energy development: Evidence based on patent counts. *International Journal of Global Environmental Issues*, *15*(3), 217–234. https://doi.org/10.1504/IJGENVI.2016.076945

Global Carbon Atlas. (2022). Global carbon atlas project. http://www.globalcarbonatlas.org/en/CO2-emissions

Global Footprint Network. (2022). *Global footprint network*. https://data.footprintnetwork.org/

Grossman, G. M., & Krueger, A. B. (1991). *Environmental impacts of a North American free trade agreement* (No. 3914). National Bureau of Economic Research, Inc.

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics*, *110*(2), 353–377. https://doi.org/10.2307/2118443

Hafeez, M., Yuan, C., Shahzad, K., Aziz, B., Iqbal, K., & Raza, S. (2019). An empirical evaluation of financial development-carbon footprint nexus in One Belt and Road region. *Environmental Science and Pollution Research International*, *26*(24), 25026–25036. https://doi.org/10.1007/s11356-019-05757-z

Hossain, M. R., Rej, S., Awan, A., Bandyopadhyay, A., Islam, M. S., Das, N., & Hossain, M. E. (2023). Natural resource dependency and environmental sustainability under N-shaped EKC: The curious case of India. *Resources Policy*, *80*, 103150. https://doi.org/10.1016/j.resourpol.2022.103150

Itoo, H. H., & Ali, N. (2022). Analyzing the causal nexus between CO_2 emissions and its determinants in India: Evidences from ARDL and EKC approach. *Management of Environmental Quality*, *34*(1), 192–213. https://doi.org/10.1108/MEQ-01-2022-0014

Jahanger, A., Chishti, M. Z., Onwe, J. C., & Awan, A. (2022a). How far renewable energy and globalization are useful to mitigate the environment in Mexico? Application of QARDL and spectral causality analysis. *Renewable Energy*, *201*, 514–525. https://doi.org/10.1016/j.renene.2022.10.081

Jahanger, A., Yu, Y., Hossain, M. R., Murshed, M., Balsalobre-Lorente, D., & Khan, U. (2022b). Going away or going green in NAFTA nations? Linking natural resources, energy utilization, and environmental sustainability through the lens of the EKC hypothesis. *Resources Policy*, *79*, 103091. https://doi.org/10.1016/j.resourpol.2022.103091

Kartal, M. T., Kılıç Depren, S., Ayhan, F., & Depren, Ö. (2022). Impact of renewable and fossil fuel energy consumption on environmental degradation: Evidence from USA by nonlinear approaches. *International Journal of Sustainable Development & World Ecology*, *29*(8), 738–755. https://doi.org/10.1080/13504509.2022.2087115

Khan, M. B., Saleem, H., Shabbir, M. S., & Huobao, X. (2022). The effects of globalization, energy consumption and economic growth on carbon dioxide emissions in South Asian countries. *Energy & Environment*, *33*(1), 107–134. https://doi.org/10.1177/0958305X20986896

Khan, S., Murshed, M., Ozturk, I., & Khudoykulov, K. (2022). The roles of energy efficiency improvement, renewable electricity production, and financial inclusion in stimulating environmental sustainability in the Next Eleven countries. *Renewable Energy*, *193*, 1164–1176. https://doi.org/10.1016/j.renene.2022.05.065

Li, B., & Haneklaus, N. (2022). Reducing CO_2 emissions in G7 countries: The role of clean energy consumption, trade openness and urbanization. *Energy Reports*, *8*, 704–713. https://doi.org/10.1016/j.egyr.2022.01.238

Li, X., Ozturk, I., Majeed, M. T., Hafeez, M., & Ullah, S. (2022). Considering the asymmetric effect of financial deepening on environmental quality in BRICS economies: Policy options for the green economy. *Journal of Cleaner Production*, *331*, 129909. https://doi.org/10.1016/j.jclepro.2021.129909

Mehmood, U., Mansoor, A., Tariq, S., & Ul-Haq, Z. (2021). The interactional role of globalization in tourism-CO2 nexus in South Asian countries. *Environmental science and Pollution Research International*, *28*(21), 26441–26448. https://doi.org/10.1007/s11356-021-12473-0

Murshed, M., Ali, S. R., & Banerjee, S. (2021a). Consumption of liquefied petroleum gas and the EKC hypothesis in South Asia: evidence from cross-sectionally dependent heterogeneous panel data with structural breaks. Energy. *Ecology and Environment, 6*, 353–377.

Murshed, M., Ferdaus, J., Rashid, S., Tanha, M. M., & Islam, M. J. (2021b). The Environmental Kuznets curve hypothesis for deforestation in Bangladesh: An ARDL analysis with multiple structural breaks. *Energy, Ecology and Environment*, *6*(2), 111–132. https://doi.org/10.1007/s40974-020-00188-w

Naveendrakumar, G., Vithanage, M., Kwon, H.-H., Chandrasekara, S. S. K., Iqbal, M. C. M., Pathmarajah, S., Fernando, W., & Obeysekera, J. (2019). South Asian perspective on temperature and rainfall extremes: A review. *Atmospheric Research*, *225*, 110–120. https://doi.org/10.1016/j.atmosres.2019.03.021

Nejati, M., & Taleghani, F. (2022). Pollution halo or pollution haven? A CGE appraisal for Iran. *Journal of Cleaner Production*, *344*, 131092. https://doi.org/10.1016/j.jclepro.2022.131092

Pata, U. K., Dam, M. M., & Kaya, F. (2022). How effective are renewable energy, tourism, trade openness, and foreign direct investment on CO_2 emissions? An EKC analysis for ASEAN countries. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-23160-z

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265–312. https://doi.org/10.1002/jae.951

Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, *60*(1), 13–50. https://doi.org/10.1007/s00181-020-01875-7

Qin, L., Malik, M. Y., Latif, K., Khan, Z., Siddiqui, A. W., & Ali, S. (2021). The salience of carbon leakage for climate action planning: Evidence from the next eleven countries. *Sustainable Production and Consumption*, *27*, 1064–1076. https://doi.org/10.1016/j.spc.2021.02.019

Sadiq, M., Kannaiah, D., Yahya Khan, G., Shabbir, M. S., Bilal, K., & Zamir, A. (2022). Does sustainable environmental agenda matter? The role of globalization toward energy consumption, economic growth, and carbon dioxide emissions in South Asian countries. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-021-02043-2

Shahbaz, M., Nasir, M. A., & Lahiani, A. (2022). Role of financial development in economic growth in the light of asymmetric effects and financial efficiency. *International Journal of Finance & Economics*, *27*(1), 361–383. https://doi.org/10.1002/ijfe.2157

Shakoor, A., Ahmed, R., Ahmed, Z., & Khan, U. (2022). Impact of subsectors of agriculture and economic growth on CO_2 emissions in Pakistan: Evidence from Environmental Kuznets Curve. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-23205-3

Sophastienphong, K., & Kulathunga, A. (2010). *Getting finance in South Asia 2010*. The World Bank Group. https://www.adb.org/publications/financial-sector-south-asia-recent-developments-and-challenges

Tillaguango, B., Alvarado, R., Dagar, V., Murshed, M., Pinzón, Y., & Méndez, P. (2021). Convergence of the ecological footprint in Latin America: The role of the productive structure. *Environmental science and Pollution Research International*, *28*(42), 59771–59783. https://doi.org/10.1007/s11356-021-14745-1

Usman, M., Anwar, S., Yaseen, M. R., Makhdum, M. S. A., Kousar, R., & Jahanger, A. (2021). Unveiling the dynamic relationship between agriculture value addition, energy utilization, tourism and environmental degradation in South Asia. *Journal of Public Affairs*, *22*(4), e2712.

Usman, O., Alola, A. A., & Saint Akadiri, S. (2022). Effects of domestic material consumption, renewable energy, and financial development on environmental sustainability in the EU-28: Evidence from a GMM panel-VAR. *Renewable Energy*, *184*, 239–251. https://doi.org/10.1016/j.renene.2021.11.086

Wang, H., & Luo, Q. (2022). Can a colonial legacy explain the pollution haven hypothesis? A city-level panel analysis. *Structural Change and Economic Dynamics*, *60*, 482–495. https://doi.org/10.1016/j.strueco.2022.01.004

Wang, X. (2021). Determinants of ecological and carbon footprints to assess the framework of environmental sustainability in BRICS countries: A panel ARDL and causality estimation model. *Environmental Research*, *197*, 111111. https://doi.org/10.1016/j.envres.2021.111111

Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics*, *69*(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

World Bank. (2022). *World development indicators*. https://databank.worldbank.org/source/world-development-indicators

Xue, L., Haseeb, M., Mahmood, H., Alkhateeb, T. T. Y., & Murshed, M. (2021). Renewable energy use and ecological footprints mitigation: Evidence from selected South Asian economies. *Sustainability*, *13*(4), 1613. https://doi.org/10.3390/su13041613

Zafar, M. W., Sinha, A., Ahmed, Z., Qin, Q., & Zaidi, S. A. H. (2021). Effects of biomass energy consumption on environmental quality: The role of education and technology in Asia-Pacific Economic Cooperation countries. *Renewable and Sustainable Energy Reviews*, *142*, 110868. https://doi.org/10.1016/j.rser.2021.110868

Zahoor, Z., Khan, I., & Hou, F. (2022). Clean energy investment and financial development as determinants of environment and sustainable economic growth: Evidence from China. *Environmental Science and Pollution Research International*, *29*(11), 16006–16016. https://doi.org/10.1007/s11356-021-16832-9

Zheng, S., Zhou, F., & Wen, H. (2022). The relationship between trade liberalization and environmental pollution across enterprises with different levels of viability in China. *Emerging Markets Finance and Trade*, *58*(8), 2125–2138. https://doi.org/10.1080/1540496X.2021.1961738