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The implications of the ecological footprint and renewable energy usage on the financial stability of South Asian countries

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Abstract

This study explores the complex relationships involving ecological footprints, energy use, carbon emissions, governance efficiency, economic prosperity, and financial stability in South Asian nations spanning the period from 2000 to 2022. Employing various methodologies such as cross-sectional dependence tests, co-integration analysis, and first- and second-generation unit-root tests, we use a panel Autoregressive Distributed Lag model, feasible generalized least squares, and Panel Corrected Standard Errors to ensure the robustness of our findings. We find noteworthy positive correlations between several variables, including heightened ecological consciousness, effective governance structures, increased GDP per capita, and amplified CO_2 emissions. These relationships suggest potential pathways to strengthen the financial stability of the entire region; they also highlight the latent potential of embracing ecologically sustainable practices to fortify economic resilience. Our results also underscore the pivotal role of appropriate governance structures and higher income levels in bolstering financial stability in South Asian countries. Interestingly, we also find negative coefficients associated with the use of renewable energy, suggesting that escalating the adoption of renewable energy could create financial instability. This finding stresses the importance of diversification in energy strategies, cautioning policymakers to carefully consider the financial ramifications of potentially costly imports of renewable energy sources while seeking to reduce carbon emissions, emphasizing the need to strike a balance between ambitious sustainability goals and the pursuit of sustained economic robustness in the region. In considering the implications of these findings, it is crucial to consider each country's broader socioeconomic context. Our results offer valuable insights for policymakers in developing renewable energy strategies.

Keywords: Financial stability, Ecological footprint, Government effectiveness, Renewable energy consumption, Economic growth, Foreign direct investment

Introduction

Financial markets are expanding globally, and increasing renewable energy use is viewed as a way to reduce obstacles to worldwide trade and foreign investment. While technological progress in renewables lowers transportation costs and improves information flows, renewable energy consumption can be boosted by political and financial changes geared toward reducing protectionist policies, modernizing foreign investment, and updating migration rules.

In the realm of global economics and environmental stewardship, the interplay among ecological sustainability, energy utilization patterns, carbon emissions, governance efficiency, economic prosperity, and financial stability is of paramount importance. The diverse landscape of South Asian nations offers a compelling canvas for exploring the multifaceted relationships among these factors that affect financial stability.

A country's ecological footprint, a holistic measure of its environmental impact, serves as a gage of the ecological boundaries within which nations operate. Climate change is highlighting the importance of understanding the relationship between an ecological footprint and financial stability to help guide policymakers in balancing economic growth and environmental sustainability. Studies such as Safi et al. (2021) and Amin et al. (2022) underscore the connection between ecological sustainability and financial stability, highlighting the significance of this relationship in the South Asian context.

Energy use patterns are equally essential in this context, considering the dual imperatives of energy security and environmental preservation. The complexities of transitioning to renewable energy sources while supporting economic growth are particularly apparent in South Asian nations, where energy demands are surging. Khan et al. (2022a) describe the challenges of managing this balance, emphasizing the need for energy policies that ensure both economic progress and financial stability. This highlights the importance of understanding the link between energy choices, economic prosperity, and financial stability.

Carbon emissions, which are closely related to energy consumption, present a dual challenge, namely environmental degradation and the potential economic repercussions of reducing energy use. Understanding the dynamics between carbon emissions and financial stability is needed to craft policies that reconcile economic growth with environmental well-being. Tharayil (2023) and Nasreen et al. (2017) show the economic merits of reducing carbon emissions, and Safi et al. (2021) and Saqib (2022) explore the relationship between carbon emissions and financial stability, analyzing consequences that ripple across economies.

Economic prosperity, which is intrinsically linked to financial stability, underscores the significance of economic growth in maintaining a stable financial environment. Safi et al. (2021) and Ellahi et al. (2021) examine the role of GDP per capita in financial stability, but Gupta (2017) caution against simplistic interpretations in such analyses, advocating for a more comprehensive view that encompasses the web of economic factors that influence financial stability. This calls for a nuanced understanding of the interplay between economic prosperity and financial stability, particularly in South Asian economies. Effective governance is another cornerstone in steering nations toward sustainable economic development. Government efficiency, often a harbinger of economic stability, is strongly related to financial well-being. The strong correlation between good governance, economic growth, and financial stability, as substantiated by Bibi and Sumaira (2022), Safi et al. (2021), and Uduwalage (2021), underscores the multifaceted role of governance in fostering economic resilience. In South Asian nations, where governance structures significantly influence economic growth and financial stability, understanding this nexus is critical for effective policy formulation. Furthermore, foreign direct investment (FDI), which has emerged as a dynamic force, is attracted by stable governance that encourages economic growth and, in turn, financial stability. Imran and Jijian (2023), Safi et al. (2021), Uduwalage (2021), and Ellahi et al. (2021) highlights the role of FDI in fostering financial stability, an assertion fortified by a consensus within the literature that showcases FDI's potential to bolster economic resilience, progress, and financial stability (Hossain et al. 2023a, b), through its potential to infuse not only capital but also technology and expertise.

South Asia has experienced tremendous economic growth since the global financial crisis of 2008. In the past decade, India's growth rate exceeded 9%, Pakistan's grew by 7%, Bangladesh and Sri Lanka grew by 6% and Nepal grew by 4%. GDP per capita in South Asian countries improved dramatically from 2000 onwards, as a result of strong economic growth and a reduction in poverty. Energy consumption is related to growth, as it reflects lifestyle trends. An increase in energy demand, particularly for renewable energy, has triggered economic growth (Rahman and Velayutham 2020; Wahab et al. 2024). In 1990, energy consumption in South Asian countries was lowered but in recent years, due to an increase in per capita income, energy consumption has increased in all three countries. Nepal is a small, moderately developed country that consumes more energy than might be expected; while Pakistan and India are both larger and more populated than Nepal, Nepal's energy use is similar to India's and Pakistan's. An increase in population can trigger an economic boom and increase energy needs in the consumer, commercial, and industrial sectors of an economy. India accounts for nearly 75% of CO_2 emissions in South Asia, although its per capita emissions are still low; there is room for significant increases with economic growth. In 2012, India's average annual CO_2 emissions per capita were 1.91 metric tons, Pakistan's was 0.94 metric tons, Bangladesh's was 0.39 metric tons, Nepal's 0.14 metric tons and Bangladesh's 0.63 metric tons (Adebayo and Kirikkaleli 2021; Agyekum et al. 2023; Akram et al. 2023; Ellahi et al. 2021). Figure 1 summarizes historical changes in the financial stability and ecological footprints of South Asian countries; darker colors indicate comparatively more financial stability and a larger ecological footprint (Adebayo and Alola 2023; Adebayo et al. (2023).

This study explores the complex landscape of ecological footprints, energy usage, carbon emissions, governance efficiency, economic prosperity, and financial stability in South Asian nations. By thoroughly examining these interconnected inputs we

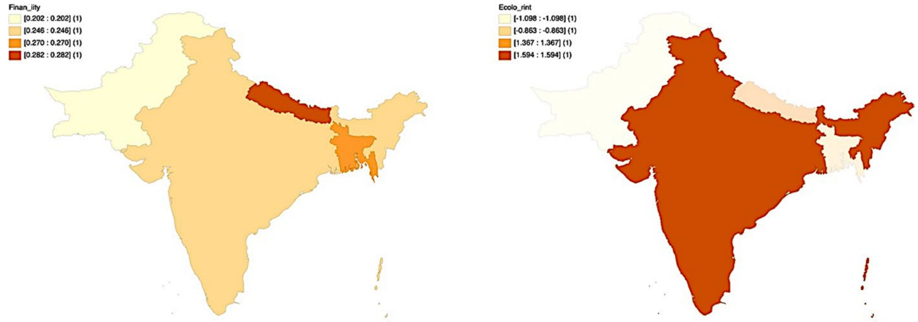

Fig. 1 Financial stability and ecological footprint in South Asia (Year: 2022)

seek to offer policymakers, researchers, and other stakeholders insights into the balance between economic advancement and ecological preservation. We employ different generations of unit-root tests—Levin-Lin, and Harris-Trazvalis, and the second-generation cross-sectional Im-Pesaran (CIPS) method—presenting the results in a consolidated table to compare their stationarity. We also incorporate tests of cross-sectional dependency and slope heterogeneity, and employ the panel Autoregressive Distributed Lag (ARDL) approach, both at an average level and tailored to individual countries. To ensure the robustness of our findings, we use feasible generalized least squares and panel-corrected standard error regressions for dependable comparisons.

The remainder of this study is organized into five parts. Sect. "Literature review" provides a literature review of relevant research on the subject. We describe our diagnostic tests, regression models, and a framework for resilient analyses in Sect. "Results and discussion". Section 4 presents the outcomes of the diagnostic tests, regression models, and robustness assessments. Finally, we conclude by summarizing our findings and providing recommendations for policy in Sect. "Conclusion".

Literature review

Financial sector development can have a positive and significant impact on environmental reliability and ecological sustainability. On the other hand, the financial sector encourages production and infrastructural development, which may increase a country's ecological footprint (Safi et al. 2021). When governments pursue policies to expand productive capacity, they usually increase income levels at the expense of a greater ecological footprint, because economic progress drives energy usage, which expands the ecological footprint and contributes to environmental degradation (Imran et al. 2022a).

Eco-energy-finance synergies

The interplay of South Asian countries' ecological footprints, renewable energy consumption, and carbon emissions has emerged as a focal point of scholarly inquiry, primarily because of the implications it holds for their financial stability. Recent studies highlight interactions that underscore the importance of developing holistic strategies for sustainable development that combine environmental preservation and economic resilience.

South Asian countries' rapid industrialization, urbanization, and unchecked exploitation of natural resources has resulted in the region's significant ecological footprint. This casts a long shadow over its financial stability, as detailed in Abbasi et al. (2023), Huang et al. (2022), and Xue et al. (2021), who underscore the dangers of unsustainable resource consumption that increases the risk of resource scarcity and subjects economies to volatility in resource prices. Their findings highlight the link between environmental degradation and the destabilization of financial systems.

Expanding on this, Islam (2021) examines the relationship between climate-related events and financial stability, showing how the aftermath of natural disasters, exacerbated by ecological imbalances stemming from unsustainable practices, can send shockwaves through financial markets. This places a substantial burden on fiscal resources, which has the potential to disturb financial stability. This is a reminder that the ecological strain of rapid development amplifies the fragility of financial systems.

Ghosh et al. (2023) and Wen et al. (2022) emphasize that businesses have a responsibility to recognize and address their ecological impacts and integrate this into their financial planning. In doing so, businesses not only contribute to environmental preservation but also fortify their long-term financial robustness. This aligns corporate strategy with sustainability, positioning enterprises for prosperity by addressing ecological challenges.

Recent developments in the South Asian region magnify the significance of these research insights. Nations such as Bangladesh and Nepal have confronted the consequences of ecological imbalances due to a heightened vulnerability to natural disasters such as floods and landslides (Ranillgado and Anand 2022; Murshed et al. 2021). These incidents have wreaked havoc on local communities while revealing the direct and indirect financial repercussions of inadequate environmental stewardship.

Alsagr (2023) examines the transformative capacity of clean energy investments within the region's financial systems, showing the mechanisms by which such investments attract sustainable capital inflows, spur technological innovations, and fortify economic resilience. The shift in investor sentiment toward long-term viability and environmental dividends not only broadens the diversity of financial portfolios, it reinforces the region's growth trajectory.

Carbon emissions, propelled by carbon-intensive industries, pose a formidable challenge to financial stability in South Asian countries. Uduwalage (2021) analyzes the environmental, regulatory, and reputational risks these industries face, which can affect their financial performance which can, in turn, have a destabilizing effect on financial markets, highlighting the connection between environmental concerns and financial stability.

Building on this, Shahbaz et al. (2022) analyze the role of carbon pricing mechanisms on financial strategies of companies in carbon-intensive sectors. By attaching a monetary cost to carbon emissions, these mechanisms incentivize companies to shift their operations toward more sustainable, low-carbon practices. This not only supports environmental aspirations, it propels the emergence of innovative, resource-efficient technologies that have the capacity to reshape economic landscapes. This underscores the potential of carbon pricing to initiate a virtuous cycle where economic viability converges with environmental responsibility.

The importance of harmonizing financial policies with carbon reduction objectives is further underscored by Kaya (2022), Zhengxia et al. (2023), and Joof et al. (2023) that highlight the pivotal roles financial institutions and regulators play in promoting ecologically conscious economic activity. Aligning financial policies with carbon reduction goals enables regulatory bodies to channel investment and lending toward cleaner technologies and industries.

In summary, the relationships among ecological footprints, renewable energy consumption, and carbon emissions within South Asian nations has profound implications for financial stability. Recognizing and navigating these dynamics is pivotal for developing effective policies that strike a balance between economic growth and environmental preservation. By fostering sustainable practices, encouraging the widespread adoption of renewable energy, and implementing strategies to curtail carbon emissions, South Asian countries can enhance their financial stability while advancing their broader development objectives. This perspective underscores the importance of collaboration among policymakers, industries, and stakeholders in navigating the complex landscape of sustainable development to ensure a resilient financial future for the region.

Fostering financial stability through governance, growth, and investment

The relationship between governance effectiveness and financial stability has emerged as a pivotal area of research, particularly within the context of South Asian nations. Various studies examine how the quality of governance directly influences financial system stability. Hussain and Rasheed (2023) emphasize the role of transparent and accountable governance structures in fostering investor confidence and mitigating financial risks. Effective governance practices such as regulatory transparency and the rule of law are key contributors to a resilient financial ecosystem. Omri and Bel Hadj (2020) examine the interplay between governance quality and environmental externalities, highlighting how a robust regulatory framework can help to manage and mitigate risks related to natural resource exploitation, thus enhancing financial stability. Sahoo and Sethi (2020) focus on the connection between governance quality, corruption, and financial vulnerabilities, underlining the critical role of strong governance in safeguarding against economic shocks.

The nexus of economic growth and financial stability in South Asian countries has garnered substantial attention in the literature because of its clear implications for sustainable development. Recent studies have explored the relationship between economic expansion and financial resilience. Sethy and Goyari (2022) analyze how sustainable economic growth can mitigate the likelihood of financial crises and promote stability by enhancing macroeconomic buffers. Amin et al. (2022) emphasize the importance of balanced growth strategies that consider not only economic dimensions but also social and environmental factors. This holistic approach aims to ensure that growth is inclusive and avoids overburdening ecological resources, thus contributing to overall financial stability. Korkut Pata et al. (2022) undertake a comprehensive analysis of the potential impact of high growth rates on income inequality, suggesting that excessive inequality may undermine financial stability. By considering these dynamics, policymakers can tailor growth strategies that foster economic stability.

FDI's role in shaping financial stability has become a growing area of interest in the South Asian context, including how foreign investment interacts with domestic financial systems. The International Monetary Fund (2021) proposes ways that central banks can enhance financial stability by accounting for environmental risks within their FDI regulations, acknowledging the potential consequences of allowing unsustainable investments. Islam (2022) delves into the effectiveness of macroprudential tools in managing systemic risks associated with FDI inflows, emphasizing the importance of a balanced regulatory approach. Islam (2021) explores the potential of climate-related financial disclosures in promoting transparency and reducing the risks associated with cross-border investments. This evolving body of research underscores the significance of responsible foreign investments in maintaining financial stability in South Asian countries.

The intersection of governance effectiveness, economic growth, FDI, and financial stability presents a multifaceted landscape for policymakers and researchers in South Asian nations. Acknowledging the complex relationships among these variables is crucial for devising strategies that prioritize transparency, sustainable growth, and responsible investment practices. By fostering robust governance, promoting balanced economic trajectories, and attracting responsible foreign investments, South Asian nations can pursue both sustainable development and a resilient financial future. An ongoing dialogue among researchers, policymakers, and stakeholders is essential to develop effective strategies that combine these critical elements of the region's stability and prosperity.

3. Research methodology

The data for South Asian countries used in this study covers the period from 2000 to 2022. Data for each country's ecological footprint is obtained from the Global Footprint Network (Data and methodology 2021) and includes data for developed land, carbon, cropland, fishing grounds, forest products, and grazing land. Other data, including GDP per capita, government effectiveness, CO_2 emissions, and FDI, comes from the World Bank's World Development Indicators (WDI 2022) and is shown in Table 1.

There is no single measure of an economy's financial stability, but we use a well-known measure to capture the essence of this attribute. The Z-score is one of the most commonly used indicators of financial stability in the literature and can be found in different forms. It is a risk measure used at the bank level to assess the likelihood of default at the individual level. Increases in the Z-score indicate a decreased likelihood of default and, thus, greater financial stability. In this context, the volatility of a bank's returns is compared to its capital buffer (Boyd et al. 1993; Boyd and Runkle 1993). A number of studies use an aggregated bank-level Z-score as a measure of country-level stability (The World Bank 2017; Khan et al. 2023). In this section, we adopt the technique of computing Z-scores at the country level to evaluate the relationship between competition and stability in South Asia. The Global Financial Development Database provides country-level Z-scores based on aggregated bank-level data. Data are provided for the years 2000 through 2022; therefore, we limit our study to this period.

Our base line model can be described as follows:

Table 1 Data sources and units of measurement

Factor	Data Source	Unit of measurement
Financial stability	Global Financial Development Database	Z-Score: It is a risk measure used at the bank level that assesses the inverse likelihood of default at the individual level of banks
Ecological Footprint	Global Footprint Network	data for built up land, carbon, croland, fishing grounds, forest products and grazing land
Renewable energy consumption	World Development Indicator	Renewable energy consumption is measured as a percentage of total final energy consumption
CO_2 emission	World Development Indicator	CO2 emission (metric tons per capita) obtained from WDI
Government Effectiveness	World Development Indicator	Government effectiveness estimate obtained from WGI world bank
GDP Per Capita	World Development Indicator	GDP divided by the number of population
Foreign direct investment	World Development Indicator	Foreign direct investment, net inflows (% of GDP) obtained from WDI

mean value of – 0.553

$$Financial\ Stability = f(Ecological\ Footprint,\ Renewable\ energy\ consumption,\ CO2,\ Government\ effectiveness,\ GDP\ per\ capita,\ Foreign\ Direct\ Inverstment) \quad (1)$$

Financial stability is a function of the impact of a country's ecological footprint, CO_2 emissions, government effectiveness (measured by a government effectiveness index, GEI), GDP per capita, the ratio of FDI a country receives in a given year, and renewable energy consumption. We assume that ecological footprint and financial stability are positively related, so that an increase in ecological footprint increases stability in the economy (Sofuoğlu and Kirikkaleli 2023). Similarly, an increase in carbon emissions also has a positive impact on financial stability. An increase in economic activity raises GDP per capita and encourages more investment, both domestic and foreign, but at the same time it increases carbon emissions. Therefore, we assume that economic growth increases per capita GDP and CO_2 emission and thus an increase in CO_2 emission and GDP per capita is positively associated with financial stability. Furthermore, government effectiveness, FDI, and renewable energy consumption all have a positive impact on financial stability. If a country has an effective government it is more likely to have a rule of law that would encourage FDI, and one additional unit of foreign direct investment improves higher financial stability by more than one unit. Additionally, due to the large number of countries included in the study we include a variable regarding renewable energy consumption to assess each country's response to global efforts to increase the use of renewable energy and its impact on financial stability.

Diagnostic tests

Before proceeding to the regression, we outline the methodology of this approach using the schematic flow in Fig. 2, which we use to define a suitable regression model.

We begin by testing for the presence of a unit-root using the Augmented Dicky Fuller test. Equation 2 includes the panel unit-root is as follows:

$$\Delta Y_{it} = \alpha_i + \rho_i X_{i,t-1} + b_i X_{t-1} + \sum_{j=0}^{k} d_{ij} X_{t-j} + \sum_{j=0}^{k} \delta_{ij} \Delta X_{i,t-1} + \varepsilon_{it} \quad (2)$$

where X_{t-1}=$\left[\frac{1}{N}\right] \sum_{i=1}^{N} X_{\text{ i,t-1}}$ and t_i=$[N, T]$ is the estimated t-statistic. Furthermore, we analyze stationarity using the cross-sectional augmented Im, Pesaran, and Shin (CIPS) method (Pesaran 2007) presented in Eq. 3. This test may be used to analyze various slope coefficients and cross-sectional independencies, but for comparison we also used

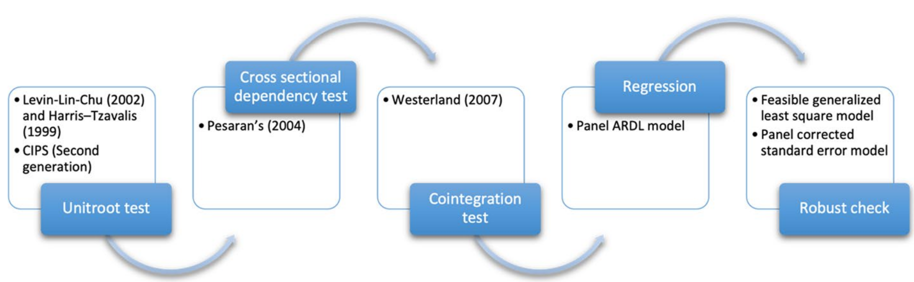

Fig. 2 Schematic of the methodological flow

first- generation unit-root tests such as Levin et al. (2002) and Harris and Tzavalis (1999). The general form of the CIPS test is as follows:

$$\widehat{CIPS} = \frac{1}{N}\sum_{i=1}^{N} CADF_i \tag{3}$$

We also test for independence in the cross-section and the absence of spillover effects as the null hypothesis, which indicates that nations are self-sufficient both at home and abroad. For this purpose, we compute the cross-sectional dependence (CSD) as shown in Eq. 4:

$$CSD_{LM-Adj} = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\hat{\gamma}_{ik}\right)\frac{(T-j)\hat{\gamma}_{ik}^2 - E(T-j)\hat{\gamma}_{ik}^2}{V(T-j)\hat{\gamma}_{ik}^2} \tag{4}$$

Co-integration is a critical concept in econometrics that helps to analyze the long-term equilibrium relationships between variables, showing whether variables will eventually move together or will tend to deviate from each other. We examine various econometric techniques and methodologies to identify and estimate co-integration relationships accurately. Westerlund (2007) provides valuable insights about co-integration analysis using rigorous statistical methods with practical implications for economic and financial research. Understanding co-integration relationships allows researchers to model and forecast variables more accurately, leading to improved decision-making, and aids in understanding the interdependencies among economic variables and their long-run dynamics. Therefore, we examine long-run relationships using Westerlund's (2007) co-integration technique, which is classified into groups (G) as shown in Equations. 5 and 6, and panels (P) as in Equations. 7 and 8.

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\alpha_i}{SE\alpha_i} \tag{5}$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\alpha_i}{\alpha_i(1)} \tag{6}$$

$$P_t = \frac{\alpha}{SE(\alpha)} \tag{7}$$

$$P_a = \mathrm{T}\alpha \tag{8}$$

Econometric approach

The form of the Panel ARDL model for country i at time t is presented in Eq. 9.

$$Financial\ Stability_{it} = \sum_{j=1}^{P}\lambda_{ij}Fin.Stab._{i-t-j} + \sum_{j=0}^{Q}\delta_{ij}'X_{i-t-j} + \mu_i + \varepsilon_{it} \tag{9}$$

where X_{it}isa$kX1$ vector related to regressor groups i, and u represents a fixed effect. The coefficient for financial stability denotes the effect on financial stability from the independent factors, λ_{ij} stands for lagged regress, and determines the scalars used in the equation. δ_{ij} is the coefficient vector. The error terms ε_{it} represent any co-integration between the regressors and regressands. The major characteristics of co-integration are a reaction to deviations from a long-term equilibrium. Similarly, the error term is a function of the regressors and regressands and indicates short-term dynamics as it is impacted by deviations. On the basis of the Panel ARDL equation, the equation for error correction is shown in Eq. 10:

$$\Delta FS_{i,t} = \emptyset_i\left(FS_{i,t-1} - \theta_i' X_{it}\right) + \sum_{j=1}^{P-1} \lambda_{ij}^{*} \Delta FS_{i,t-1} + \sum_{j=0}^{Q-1} \delta_{ij}^{\prime *} \Delta X_{i-t-j} + \mu_i + \varepsilon_{it} \tag{10}$$

where $\varnothing_i = -\left(1 - \sum_{j=1}^{P} \lambda_{ij}\right), \theta_i = \sum_{j=0}^{Q} \frac{\delta_{ij}}{(1-\sum_k \lambda_{ik})}$ $\lambda^*{}_{ij} = -\sum_{m=j+1}^{P} \lambda_{im}$ and $\delta^*{}_{ij} = -\sum_{m=j+1}^{Q} \delta_{im}$, where $i = 1, 2, 3, \ldots, P-1, andj = 1, 2, 3, 4, \ldots, Q-1$.

In Eq. 10, $\varnothing_i$ is the error correction speed. If this is equal to zero, then no long-run will occur in these regressed and regressors, as returning to a long-run equilibrium is seen as an error in this model. The term θ_i' in Eq. 10 shows there is a long-term relationship between the regressands and regressors.

Pesaran and Smith (1995) develop an estimator known as the panel data mean group that can be used as an error correction for groups of countries. It uses slopes of the confidence levels related to variables and their intercepts. Pesaran et al. (1999) and Chudik et al. (2023) also develop the pooled mean group estimator for panel data. This method includes intercepts and coefficients that are related to variables in the short run and error variations that are not similar across countries, while the coefficients of regressors in the long run are similar among different country groups.

We employ the feasible generalized least squares (FGLS), a practical version of the generalized least squares method, and panel-corrected standard errors (PCSE) regression models as robust techniques. The FGLS model accommodates cross-sectional error dependencies by incorporating average cross-sectional returns as the response variable, and their respective lags (Greene 2017; Maddala and Lahiri 2006).

When the covariance matrix of the error terms, denoted as Ω, is unknown but is a nonsingular covariance matrix of x, one can obtain a consistent estimate of Ω, denoted as $\widehat{\Omega}$, using known as the (FGLS) estimator. The matrix Ω is of size $nt \times nt$ and is composed of multiple block matrices. Each (t,s) block represents an $n \times n$ covariance matrix denoted as $Eu_t\acute{u}_s$. In this study, we employ the following FGLS estimator for β, shown in Eq. 11:

$$\hat{\beta}_{FGLS} = \left(\acute{X}\Omega^{-1}X\right)^{-1} \acute{X}\Omega^{-1}YF \tag{11}$$

The PCSE regression method is used in a panel data analysis to address heteroscedasticity (unequal variances) and serial correlation (correlation between error terms) that commonly arise in these datasets. The PCSE regression model accounts for serial correlation and heteroscedasticity by adjusting the standard errors of the coefficients in the regression equation. To produce more accurate and efficient estimates of the coefficients,

Table 2 Descriptive statistics

	Financial stability	Ecological footprint	Renewable energy consumption	CO_2 emission	Government effectiveness	GDP per capita	Foreign Direct Investment
Number	84	84	84	84	84	84	84
Mean	2.827101	−.1515011	3.907262	−.685784	−.5638605	6.717128	−.2804887
Median	2.844619	−.1552117	3.84631	−.4901816	−.7	6.792639	−.1425543
Std. dev	.3625387	.1913244	.3567995	.8292801	.3436099	.5631144	1.018285
Skewness	−.2229668	−.3701769	.3944055	−.3351875	.9459644	−.4009741	−1.661989
Kurtosis	2.532887	3.234911	2.158398	2.023384	2.971352	2.347595	7.533776

Table 3 Unit-root test

Variable	Levin-Lin- Chu unit-root test		Harris-Tzavalis Unit Root		CIPS	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
Financial stability	−3.0066***	−2.1283***	0.3272***	−0.1602***	−3.740***	−4.700***
Ecological footprint	−0.3216	−3.2904***	0.6867	−0.0274***	−1.346	−4.365***
Renewable energy consumption	0.9154	1.2772	0.8142	0.3894***	−1.378	−4.613***
CO_2	−0.6162	−0.6927	0.7245	0.0325***	−1.670	−4.613***
Government effectiveness	−1.3557**	−2.8405***	0.5574	−0.2252***	−3.097**	−5.330***
GDP per capita	0.5886	−4.0818***	0.8700	0.2669***	−2.050	−4.037***
Foreign direct investment	−1.0892	−4.7956***	0.1342***	−0.5199***	−1.855	−3.828***

the PCSE technique creates robust standard errors that consider the correlation structure within the panel data. As a result, PCSE regression offers reliable statistical conclusions and more precise hypothesis testing (Greene 2017).

To obtain reliable results and validate the findings of Panel ARDL, we employ the PCSE model as follows:

$$y_{it} = \beta_0 + \beta_1 x_{1,it} + \beta_2 x_{2,it} + \ldots + \beta_k x_{k,it} + u_{it} \tag{12}$$

Results and discussion

Descriptive statistics for selected variables are listed in Table 2. We see that GDP per capita has a mean value of 953.5, average renewable energy consumption is 49.35, average financial stability with 17.9, and so on, whereas only the government effectiveness index has a negative.

Next, we conduct a sequence of panel unit-root tests including the first-generation Levin-Lin-Chu unit-root test and the Harris-Tzavalis test, followed by the second-generation CIPS test, as shown in Table 3. Across all three tests, most of the variables are significant when using first differences, while financial stability and Government Effectiveness are significant at their own levels.

Comparing the results of the conventional first-generation unit-root tests with those of the more advanced second-generation CIPS test offers a more complete understanding of the stationarity tendencies each variable exhibits. Financial Stability, Ecological Footprint, CO_2, and FDI consistently indicate a likelihood of stationarity at

Table 4 Cross-sectional dependency test

Variable	CD-test	corr	abs(corr)
Financial stability	7.297***	0.65	0.65
Ecological Footprint	5.744***	0.51	0.51
Renewable energy consumption	8.741***	0.78	0.78
CO_2 emission	9.443***	0.84	0.84
Government Effectiveness	7.61***	0.58	0.15
GDP Per Capita	10.758***	0.86	0.86
Foreign Direct Investment	−.383	−0.03	0.39

Table 5 Co-integration test

Statistic	Value	Z-value	P-value
Gt	−4.222	−3.979	0.000
Ga	−0.684	2.876	0.009
Pt	−1.489	1.861	0.000
Pa	−0.536	1.885	0.006

I(0) across all tests. On the other hand, Renewable Energy Consumption and Government Effectiveness introduce varying degrees of change, indicating the potential for non-stationarity (I(1)) or weaker stationarity). Importantly, GDP per capita exhibits stationarity (I(0)), supported by both the Harris-Tzavalis and CIPS tests, with additional support from the Levin-Lin-Chu test. By incorporating these diverse tests we gain insights into the stationarity of each variable, which improves the reliability of the econometric analyses.

We use Pesaran's (2007) CSD tests to identify whether cross-sectional dependency exists among the countries listed in Table 4. The results of the tests for specific variables and average correlation coefficients are shown, and the CSD statistics and p-values significantly reject the null hypothesis of cross-sectional independence, with cross-correlations significant at the 1% level, implying that cross-sectional relationships exist among the countries in our sample, except with respect to FDI, whose CSD values are not significant. This result indicates that FDI does not have cross-sectional dependency among South Asian countries.

Next, we use the co-integration technique in Westerlund (2007) to determine whether the data exhibit long-run relationships. The results of the co-integration are listed in Table 5 and are classified as Gt, Ga, Pt, and Pa. The results in Table 4 show that all of the group and panel test statistics significantly reject the null hypothesis of no co-integration, providing clear evidence for the existence of error correction both for panel and group statistics.

The results of the regression model, shown in Table 6, are divided into short- and long-run measures. The indicator "D" with represents a lag order one, while the lower part represents the magnitude of the impact on financial stability. The estimated coefficients and their corresponding standard errors are reported for each variable. The Error Correction Term (ECT) plays a vital role by indicating the speed at which

Table 6 Panel ARDL model average and country-specific results

Variables	(1)	(2)	(3)	(4)	(5)
ECT	− 0.960***	− 0.517**	− 1.474***	− 0.302***	− 0.412***
	(0.203)	(0.228)	(0.205)	(0.0949)	(0.147)
D.Ecological Footprint	1.780**	2.080*	0.627***	0.265**	1.768**
	(1.061)	(1.258)	(0.555)	(0.614)	(0.859)
D.Renewable energy consump:	− 1.045	3.542**	2.108*	0.125***	− 2.220***
	(1.070)	(1.418)	(1.221)	(0.591)	(1.439)
D. CO_2 emission	0.410	3.571**	0.955**	2.926***	− 1.582
	(0.949)	(1.531)	(0.436)	(0.722)	(0.723)
D.Government Effectiveness	5.611***	− 0.103***	0.0489***	0.220***	0.153***
	(0.1002)	(0.106)	(0.0389)	(0.0641)	(0.0849)
D.GDP per Capita	1.0240**	− 0.624***	0.164***	1.263***	1.097**
	(0.513)	(0.550)	(0.208)	(0.384)	(0.437)
D.Foreign Direct Investment	0.1008*	− 0.0193**	0.0402	0.0581*	0.0778**
	(0.1074)	(0.0504)	(0.0360)	(0.0508)	(0.0614)
Ecological Footprint	0.722*				
	(0.431)				
Renewable energy consumption	− 1.510***				
	(0.496)				
CO_2 emission	− 0.772***				
	(0.167)				
Government Effectiveness	0.0237				
	(0.0274)				
GDP Per Capita	− 0.152				
	(0.107)				
Foreign Direct Investment	− 0.0449**				
	(0.0226)				
Constant		0.286**	1.106***	0.238***	0.257**
		(0.116)	(0.312)	(0.0842)	(0.119)

Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

deviations from equilibrium are corrected. Here, the negative coefficient of the ECT suggests there is a corrective mechanism in place that restores financial stability in response to shocks. This finding is significant for South Asian economies because it implies that deviations from a trend toward long-term financial stability will be gradually corrected, helping to maintain a stable financial environment.

Starting from column 1, we see the size of a country's ecological footprint is positively associated with financial stability in South Asian economies (Global financial development database 2017; Gungor and Sari 2022). This suggests that a more ecologically conscious approach to development, possibly driven by sustainable practices and responsible resource management, can positively contribute to financial stability (Imran et al. 2020; Wahab et al. 2024). This finding should encourage policymakers in South Asian countries to view environmental sustainability as a potential contributor to overall economic stability (Li et al. 2023a; Wu et al. 2023). The most important positive contributor to government effectiveness across all South Asian economies is financial stability (Uhde and Heimeshoff 2009; Luo et al. 2023b). This implies that stronger and more efficient governance structures can significantly contribute to financial stability (Jiang and Xu 2023; Wang et al. 2023). For South Asian nations, this underscores the importance of transparent and capable governance systems in promoting economic resilience (He et al. 2023; Qiao et al. 2023). An increase in GDP per capita is the third highest positive contributor to financial stability, while the fourth largest contributor to financial stability is an increase in CO_2 emissions (Kong et al. 2023; Li et al. 2023b), which increases with the level of industrial production. The analysis suggests that increase in CO_2 emission causes financial stability, which implies that efforts to control and reduce CO_2 emissions might have differing effects on financial stability across these economies (Luo et al. 2023a, 2024). FDI has the smallest impact on financial stability in South Asian economies, but an influx of FDI can have a positive impact (Mazhar and Majeed 2022; Samour et al. 2023).

Renewable energy consumption, on average, is the only negative contributor to financial stability across these South Asian economies (Shang et al. 2023). The negative impact might be due to the high upfront cost of most renewable sources. South Asian economies should find sources of funding for renewable energy production to tackle financial instability.

In conclusion, the results in Table 5 provide insights into the impact of a range of factors affecting financial stability in South Asian economies. These impacts are diverse and interconnected (Imran et al. 2022b), and policymakers in these economies should carefully consider these findings to develop strategies that foster economic growth while maintaining a stable financial environment. It is important to note that these implications are derived from a statistical analysis and should be complemented by an understanding of the broader economic, social, and political context of each country.

Table 6 presents individual country analyses. Columns 2 to 5 provide insights into the impact of our factors on financial stability in Pakistan, Bangladesh, India, and Nepal, with implications for economic policies in these countries. The ECT coefficient reflects the long-term equilibrium relationship between variables. The negative coefficients across all countries suggest that deviations from the equilibrium relationships are corrected over time. This implies that any imbalance in the short run converges toward a stable long-term equilibrium. This finding indicates a strong tendency toward financial stability in these economies.

Here, we discuss the country-level findings for the individual factors:

Ecological footprint: The positive coefficients for Pakistan, Bangladesh, and Nepal indicate that an increase in their ecological footprints positively affects financial stability, consistent with the graphs in Fig. 3 (Imran et al. 2022c). This suggests that countries focusing on ecological sustainability may experience improved financial resilience. However, India's coefficient is not statistically significant, implying that its financial stability may not be directly linked to ecological factors (Ellahi et al. 2021). Policies promoting environmentally conscious practices can enhance economic stability (Imran et al. 2022c; Mahmood 2020).

Renewable energy consumption: Bangladesh and India show positive and significant coefficients for this factor, as shown in Fig. 4, suggesting that higher renewable energy consumption contributes to financial stability in these countries (Bibi and Sumaira 2022). This aligns with the notion that renewable energy can bolster energy security and economic resilience (Mahmood 2022a; Imran et al. 2019). Nepal's coefficient is

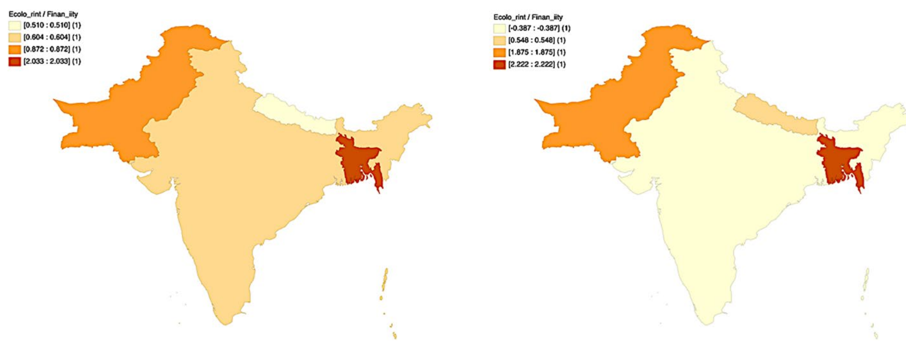

Fig. 3 Change in ecological footprint to financial stability from 2000 to 2022

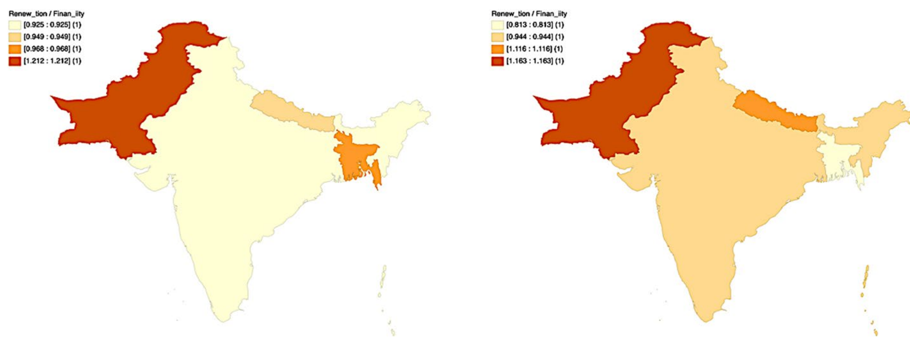

Fig. 4 Change in renewable energy consumption to financial stability from 2000 to 2022

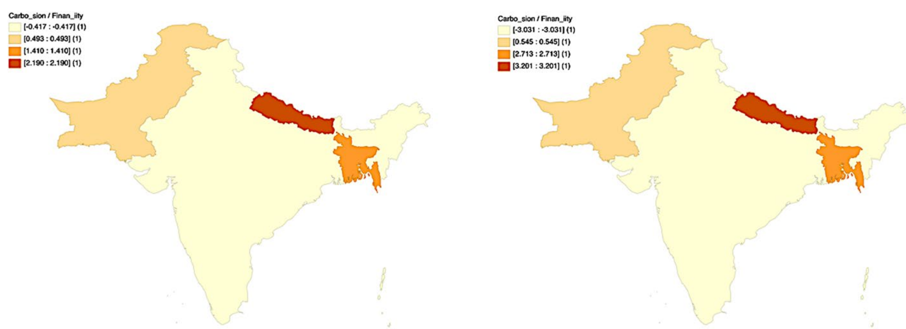

Fig. 5 Change in carbon emissions to financial stability from 2000 to 2022

positive but not significant, whereas Pakistan's coefficient is negative, indicating a complex relationship with renewable energy (Khan et al. 2022b; Uduwalage (2021); ; ; ; ;.

CO_2 emissions: The coefficients for Bangladesh, India, and Nepal are positive and significant, as shown in Fig. 5, indicating that increased CO_2 emissions are associated with financial stability (Safi et al. 2021 and Kumar et al. 2022). However, high CO_2 emissions have negative environmental and long-term economic implications (Mohammad et al. 2022). Pakistan's coefficient is positive but not significant.

Government effectiveness: The positive and significant coefficients across all countries indicate that better government effectiveness fosters financial stability (Bibi and

Sumaira 2022; Safi et al. 2021; Uduwalage 2021). This underscores the importance of transparent governance and efficient government policies to attract investment and support economic resilience (Samour et al. 2022; Wahab et al. 2022).

GDP per capita: The positive coefficients for Bangladesh, India, and Nepal signify that higher GDP per capita contributes to financial stability (Safi et al. 2021; Ellahi et al. 2021). This is consistent with the understanding that increased prosperity can translate into greater economic resilience (Wahab et al. 2023; Mahmood 2022b). However, Pakistan's coefficient is positive but not significant.

Foreign direct investment: The positive coefficients for Pakistan, Bangladesh, and India suggest that higher levels of FDI can enhance financial stability (Ellahi et al. 2021; Mahmood et al. 2023b). This agrees with the positive impact of FDI on economic growth and resilience. Nepal's coefficient is positive but not significant (Mahmood et al. 2023a; Ali et al. 2022).

Based on these results, South Asian countries should prioritize policies that enhance ecological sustainability, as a positive ecological footprint positively influences financial stability. Emphasizing the transition to renewable energy, especially in Bangladesh and India, can enhance financial stability while promoting energy security and sustainability. While increased CO_2 emissions might contribute to financial stability in the short-term, policymakers should balance economic growth with environmental preservation to reduce long-term risks. Improving government effectiveness is crucial in attracting FDI, fostering economic growth, and promoting financial stability. Strategies aimed at increasing GDP per capita can contribute to financial stability, particularly in Bangladesh, India, and Nepal. Creating an investor-friendly environment to attract FDI can bolster financial stability across countries.

The findings from the robust Feasible Generalized Least Squares (FGLS) analysis and panel-corrected standard errors (PCSE) listed in Table 7 offer insights into the interactions between various factors and financial stability within South Asian economies.

Table 7 Robust analyses

	(1)	**(2)**
Variables	FGLS	PCSE
Ecological Footprint	1.353***	1.747***
	(0.200)	(0.337)
Renewable energy consumption	−0.227*	−0.281*
	(0.122)	(0.168)
CO_2 emission	−0.486***	−0.630***
	(0.0735)	(0.112)
Government Effectiveness	−0.00582**	−0.0102***
	(0.0339)	(0.0424)
GDP Per Capita	−0.0389***	0.227***
	(0.112)	(0.186)
Foreign Direct Investment	0.0330**	0.0127***
	(0.0241)	(0.0383)
Constant	0.0980**	−0.00957***
	(0.0462)	(0.0733)

Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

These results hold particular significance for policymakers seeking to understand how these factors affect financial stability. By examining the influence of each variable and its implications for the financial stability of these economies, these findings provide a solid foundation for informed policy decision-making. In addition, a comparison with the results shows in Table 5 presents a broader understanding of the driving forces behind financial stability in the region.

The positive coefficients attributed to the ecological footprint variable in both the FGLS and PCSE models highlight a notable correlation between a larger ecological footprint and heightened financial stability (Bansal et al. 2021; Amin et al. 2022). This correlation, which is consistent across our robustness analyses, is consistent with Shastri et al. (2018) who find potential benefits to economic resilience from pursuing environmentally sustainable practices.

The negative coefficients for CO_2 emissions in both models indicate that reducing emissions could contribute to greater financial stability (Bansal et al. 2021; Amin et al. 2022). This not only confirms the potential benefits of environmental stewardship, it aligns with the literature emphasizing the economic advantages of reducing CO_2 emissions and fostering sustainable practices (Tharayil 2023; Nasreen et al. 2017). Policymakers should regard these findings as a call to action to pursue both environmental consciousness and financial stability in their strategies. The negative coefficients for renewable energy consumption, which should reduce CO_2 emissions, suggest a complex relationship between energy use and financial stability. (Bansal et al. 2021; Amin et al. 2022). While transitioning to renewable energy sources remains crucial from an environmental standpoint, our results suggest that financial stability may face challenges in making this transition. This is consistent with recent studies that emphasize the importance of balancing energy transition policies with economic growth (Khan et al. 2022b), and underscores the need for policymakers to adopt a holistic view that embraces renewable energy while safeguarding financial stability.

The negative coefficients associated with government effectiveness are intriguing (Bansal et al. 2021; Amin et al. 2022). The robustness of this result indicates a complex relationship between governance efficiency and financial stability, which is consistent with the findings in Nasreen et al. (2017). The varying coefficients for GDP per capita in the FGLS and PCSE models indicate complexities also exist in this relationship (Bansal et al. 2021; Amin et al. 2022). A comparison with the robust results highlights the need to avoiding oversimplifying the link between income levels and financial stability (Gupta 2017). Policymakers should approach this finding as a reminder to consider a wide range of economic factors to promote financial stability.

The positive coefficients for FDI in both models underscore the role of FDI in enhancing financial stability across different analytical approaches, which is consistent with Bansal et al. (2021) and Amin et al. (2022). This finding also agrees with Hossain et al. (2023a, b) who emphasize FDI's potential to drive not only economic growth but also financial resilience. The robust results highlight the significance of FDI as a stabilizing force in these economies.

In summary, the insights garnered from the robust FGLS and PCSE analyses, along with a comparison to the results in Table 5, provide a comprehensive framework for understanding the multifaceted relationship between the factors studied here and financial stability within South Asian economies. These findings are consistent with other recent studies that underscore the interconnectedness among environmental responsibility, renewable energy, governance effectiveness, GDP per capita, FDI, and financial stability (Hossain et al. 2023a, b; Bansal et al. 2021). Policymakers can used these insights to develop informed strategies that bolster economic growth and support a resilient and stable financial environment.

Conclusion

This study investigates the impact of ecological footprints, renewable energy consumption, CO_2 emissions, government effectiveness, GDP per capita, and FDI on the financial stability of selected South Asian countries (Pakistan, India, Bangladesh, and Nepal) from 2000 to 2022. We employ several analytical techniques such as the CSD test (Pesaran et al. 2013), Westerlund's (2007) co-integration, and both first- and second-generation (CIPS) unit-root tests, namely Levin et al. (2002) and Im et al. (2003). After finding CSD and co-integration in the data, we use the Panel ARDL model to analyze the impact of the independent factors on the financial stability of South Asian countries, which provides valuable insights into the relationships among these factors and how they affect economic resilience in these countries. We also use the FGLS and panel corrected standard errors regression models to confirm the results of the primary regression model. Overall, the findings reveal the complex interplay among these factors and their varying contributions to financial stability across the region.

The analysis presented here indicates these factors significantly influence financial stability in South Asian economies. First, a positive association between ecological footprint and financial stability suggests that environmentally conscious practices can enhance economic resilience. This highlights the potential for sustainable resource management to contribute to overall financial stability and underscores the need for policies that emphasize environmental sustainability. Governance systems, as evidenced by their positive correlation with government effectiveness, play a major role in maintaining financial stability. Transparent and capable governance structures are essential to economic resilience. GDP per capita has a positive correlation to financial stability, indicating that rising income levels can positively impact economic resilience. However, the negative coefficient for Pakistan suggests the presence of other influences in this relationship. CO_2 emissions are a positive contributor to financial stability, with the analysis indicating that efforts to control emissions may have varying effects on stability across economies. Foreign direct investment has a weaker but positive influence, suggesting that policies to promote FDI could enhance overall economic stability. Conversely, renewable energy consumption is shown to have a negative influence, suggesting a need for additional analysis to explore whether this is due to the high cost of renewable energy sources. These findings underline the importance of balancing environmental concerns and economic stability in policy decisions and indicate ways to foster resilience in South Asian economies.

Our analysis of factors that contribute to financial stability in four South Asian countries reveal that ecological sustainability positively influences financial resilience in Pakistan, Bangladesh, and Nepal, while renewable energy consumption positively impacts financial stability in Bangladesh and India. In contrast, CO_2 emissions are positively associated with financial stability in Bangladesh, India, and Nepal. Effective governance contributes to financial stability in all countries, a higher GDP per capita is positively correlated with financial stability in several of the countries in the study, and FDI positively affects financial stability in Pakistan, Bangladesh, and India. Our results underscore the need for context-specific policies to balance environmental and economic priorities for long-term financial stability in South Asian economies.

In conclusion, our analysis contributes to the understanding of the multifaceted dynamics that impact financial stability in South Asian economies. These insights can be useful to policymakers in making informed decisions that align environmental imperatives with economic growth and a resilient and stable financial environment.

Study limitations

Our study's timeframe and focus on specific countries might restrict its generalizability. Relying on secondary data sources could introduce biases, and while we employ robust methodologies certain assumptions are still embedded in the analysis. Omitted variables such as geopolitical influences, and the complexity of causal relationships could limit our findings. Recognizing the contextual nature of the results, we encourage a cautious interpretation when applying them within each country's socioeconomic context. Despite these limitations, our study contributes to the literature by shedding light on the intricate dynamics affecting financial stability in South Asia, paving the way for future research to incorporate more variables and employ other advanced methodologies to contribute to a more comprehensive understanding.

Policy recommendations

Based on our findings, we offer the following policy recommendations for South Asian countries:

1. Recognize the positive association between ecological footprint and financial stability. Prioritize policies that encourage the sustainable use of resources, improve waste management and reduce carbon emission reduction. By implementing effective environmental regulations, South Asian nations can safeguard their long-term economic resilience.
2. Acknowledge the critical role of transparent and efficient governance in maintaining financial stability. Develop and enforce policies that enhance accountability, transparency, and institutional capabilities. Strengthening governance structures will mitigate risks and significantly contribute to overall economic resilience.
3. Address the challenge of renewable energy consumption's negative correlation with financial stability. Develop comprehensive policies that facilitate the transition to renewable energy sources while addressing potential economic barriers. Incentivize domestic production of renewable energy to reduce dependence on imports and enhance energy security.
4. Acknowledge the diverse effects of CO_2 emissions on financial stability. Craft emission control strategies that consider the unique economic contexts of each country. Encourage industries to adopt cleaner technologies and support initiatives that align emission reduction with economic goals.

5. Emphasize the importance of an integrated policy approach that considers the complex interactions among key variables. Develop policies that strike a balance between environmental sustainability and economic stability to strive for policies that are coherent, holistic, and align with national development objectives.

Overall, policymakers should prioritize sustainable development, promote renewable energy, reduce carbon emissions, enhance governance, and ensure that economic growth benefits all segments of society. By implementing these policy recommendations, South Asian countries can enhance their financial stability and promote sustainable and inclusive growth.

Abbreviations

CO_2	Carbon dioxide
ARDL	Autoregressive distributive lag model
GDP	Gross domestic product
CIPS	Cross-sectional Im Pesaran
CSD	Cross sectional dependence
FGLS	Feasible generalized least square
PCSE	Panel correct standard error
ECT	Error correction term

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Author contributions
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Data availability
The article does not include any kind of unauthorized, restricted, or illegal material and data. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests
The author(s) declare(s) that they have no competing interests (both financial and non-financial).

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