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Integration of ecological innovation, institutional governance, and human capital development for a sustainable environment in Asian Countries

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ABSTRACT

The study evaluates the dynamic influence of institutional quality, green innovation, and human capital on the ecological footprint in South Asian countries from 1990 to 2018. For empirical estimation of panel data, the study applied the cross-section autoregressive distributed lag (CS-ARDL) estimator to address the issues of cross-section dependency and slope heterogeneity. The long-run findings reveal that institutional governance and ecological innovation reduce the ecological footprint. Likewise, human development decreases the ecological footprint. The short-run outcomes are identical to the long-run; however, the short-run estimates' magnitude is smaller than the long-run. The results also support the Environmental Kuznets Curve Hypothesis in the long run. The error correction term (ECT) with a significant negative value endorsed the conversion towards the long-run equilibrium position with a 26.5% annual adjustment rate in case of short-run deviation. The augmented mean group estimator ensures the robustness of estimates. The findings recommend that South Asian economies should promote green technology and human capital through R&D allocations in industrial and academic sectors.

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1. Introduction

Environmental sustainability and climate risks are the biggest hazardous consequences posing the contemporary world due to excessive dependence on fossil fuels for energy consumption. Thus, using traditional energy sources generates carbon emissions that cause global warming and climate change. These emissions cause droughts, heavy snowfall, floods, and heat waves which are adverse environmental consequences (Wang et al., 2022). Therefore, the Conference of Parties (COP26) instigate to limit global temperature below 1.5 °C to cope with the excessive energy demand in growing

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economies. The rising ecological damages have gained the attention of policymakers and scholars toward the mitigating factors that reduce environmental breakdowns and encourage sustainable development without deteriorating the environment (Irfan et al., 2022). Governments take many policies and non-policy initiatives to address climate vulnerability, and sustainable technologies are one of them (Xuefeng et al., 2022).

Climate or green technology is a significant determinant in encouraging the green development of global economies (Du et al., 2019). Eco-technology is a novel technological innovation that promotes sustainable environmental quality and green economic growth by diminishing intensive energy usage and mitigating pollutant emissions. There are various techniques of ecological technologies, including biomass processing, recycling, waste disposal management, clean and green energy sources, carbon capture and storage technology, electric automobiles, bio-nanotechnology, green buildings, and environment-related green management (Razzaq et al., 2021). The concept of green innovation is different from conventional technology in that it produces two externalities; it not only spreads the knowledge spillover effect but also generates positive externalities for the environment (Yuan et al., 2022).

Two groups of studies exist in the literature about the nexus between eco-innovation and environmental degradation. One group claims that clean technologies inhibit carbon emissions and provide the optimal solution for reducing environmental pollution in developing countries (Khan et al., 2020; Wang et al., 2020). Green innovation increases resource efficiency by replacing non-renewable energy resources with green or clean energy sources. In addition, these innovations reduce the demand for energy consumption, and thus less energy is consumed in production. It will raise energy efficiency and reduces production cost in terms of energy saving. It raises productivity and stimulates the competitive advantage in production, and thus optimal output is produced. Further, ecological innovation decreases environmental hazards, diminishes pollution, and enhances environmental quality. The indirect advantages of renewable technologies comprise individuals' good health and businesses' financial performance (Lingyan et al., 2022).

The second group argued that clean technologies have no significant influence on environmental performance (Khattak et al., 2020; Weina et al., 2016). The positive spillover influences of eco-innovation are changed in different economies because of varied economic conditions and developments. Thus, in low-income countries, the impacts of green technology are negligible, while they profoundly influence high-income countries on the mitigation of carbon pollution. The other cause of little impact lies that developing nations have no sufficient resources in the form of skilled human resources and renewable energy investment. The lacking of human and physical capital produces a technological gap between developed and non-developed countries. Therefore, it would not boost the promotion and usage of eco-innovation and ultimately reduces pollution (Chen et al., 2022).

Apart from innovations, human development is considered an intangible asset in the form of skills, knowledge, and experiences that promote environmental innovation and quality. Many studies have ascertained the direct effect of human resources in stimulating ecological sustainability (Huang et al., 2021; Jin et al., 2021). Through education, human resource has the potential to produce positive environmental impacts. Educated people are well-informed about the use and significance of green energy sources; thus, they consume and encourage eco-friendly products in their lifestyles. In industrial production, human capital is supported with the latest technology and skills, increasing labor productivity and energy efficiency (Shao & Razzaq, 2022). Thus, efficiency gain demands low energy and produces less energy-intensive and productive products. However, some studies documented the positive role of human resources in damaging the environment (Halliru et al., 2020; Yañez et al., 2019). For high human development, more educational centers and training institutes are needed. The establishment of such institutions demands energy resources that cause environmental damage. In addition, the developing economies have low technical skills in human resources, which must be a prerequisite for advanced production methods in manufacturing industries. Besides eco-innovation and human capital, institutional governance offers an interface where all stakeholders react to different policies and measures.

Institution refers to rules in interpersonal interactions, systems, and organization mechanisms comprising formal and informal institutions (Yuan et al., 2022). Higher institutional quality denotes the development of systematic and efficient policies by government agencies to support economic growth and environmental conservation. These regulations can make the company and human behavior more predictable, reduce operational costs, and increase economic performance and environmental protection advantages. Strong institutional quality thus contributes to economic development and environmental quality improvement. Few discussed the negative role of institutional quality on environmental deterioration (Haldar & Sethi, 2021; Katircioglu et al., 2020). Institutions are in a far better position to control environmental degradation through democracy and strict environment-related policies. Effective and strong political institutions reduce transaction costs and asymmetric information, increase economic and market efficiency and enhance the benefits of environmental protection. Internalizing pollution-related negative externalities and imposing taxation and subsidies are the direct benefits of political institutions. The indirect advantages formulate policies that produce energy efficiency in consumption and production. Moreover, high-quality institutions reduce corruption which is responsible for all evils in controlling carbon emissions. Also, solid political institutions affect the environment by facilitating high-income quality and power distribution.

In comparison, some studies found a direct link between institutional quality and environmental damage (Azam et al., 2021; Teng et al., 2021). Most developing economies have weak political institutions, and corruption is the main factor that resists the regulation of environmental control. Thus, low institutional quality is directly linked to corruption (Hassan et al., 2020). The second reason behind the positive association between the two variables is that non-developed economies are enriched with natural resources and highly dependent on traditional energy sources for energy usage. For high economic growth, these nations focused more on industrial activities that raise energy consumption and emit higher carbon emission levels (Azam et al., 2021).

Although many prevailing research studies have separately analyzed the nexus between green innovation, human resources, political institutions, and environmental quality, thus, no study integrates all these crucial factors in a multidimensional framework. Most previous studies have taken a single proxy of institutional quality, such as law and order (Obobisa et al., 2022). The single proxy usually captures the partial impacts of institutional quality and produces unreliable results. Thus, the current study calculated the cumulative index of institutional quality using principal component analysis (PCA) by integrating the absence of violence, control of corruption, the rule of law, regularity quality, political stability, and voice and accountability. Therefore, the index is a reliable measure to represent the influence of political institutions on environmental performance. The study chooses South Asian economies because of the highest environmental vulnerability compared to other regions. Moreover, the region is facing the worst global warming crisis due to its geographical location (Sultana et al., 2022; Sun et al., 2021). The challenges of both climate change and global warming emerge from environmental damage. In addition, South Asian countries belong to the low-income group and cover one-fifth of the world's population. Thus, the region is abundant in human resources, and its vulnerable environmental position needs attention for immediate solutions to promote environmental sustainability with economic development. The proposed association is observed under the framework of EKC using a cross-sectional autoregressive distributed lag (CS-ARDL) model. The CS-ARDL is a more preferred approach than traditional panel data methods; because it is superior in dealing with the issues of cross-section dependency (CSD) and slope heterogeneity. Therefore, consistent and robust results are produced by using this approach. Lastly, the augmented mean group (AMG) estimator is used to check the reliability of the estimates.

The current study's structure is formulated as follows: section two demonstrates the literature of the previous studies, section three describes the methodology and data, followed by results and discussion in section four. Finally, section five represents the conclusion and policy implications.

2. Literature review

2.1. Human capital & environment

Many studies have investigated the linkage between human development and environmental deterioration. Some studies explored the direct positive impacts of human resources in improving environmental quality. Ahmed and Wang (2019) emphasized human resources' contribution to India's ecological footprint from 1971 to 2014. The study concluded that human capital oppositely influences the ecological footprint. Bano et al. (2018) used country-specific data of Pakistan from 1971 to 2014 to explore human development's influence on ecological quality, documented that the human capital is downscaling carbon emissions without compromising economic prosperity, and revealed the long-run causal association between them. Huang et al. (2021) used a spatial panel lag model and quantile regression model to assess the potential of HC on carbon mitigations by utilizing provincial data of China over the period 1998 to 2017. The findings revealed that all types of human resources enormously contribute to reducing carbon emissions in selected regions. Jin et al. (2021) used the Quantile ARDL technique to analyze the impacts of human development and ecological innovation on carbon emissions in China from 1988 to 2018. The results exhibited that eco-innovation and human capital reduce ecological damage significantly from lower to medium quantiles and from medium to higher quantiles.

Çakar et al. (2021) researched the nexus between human resources and environmental degradation in twenty-one European nations from 1994 to 2018. The authors found that human capital reduces environmental breakdown in low-growth regimes while they increase in high-growth regimes; thus, the study suggests that along with economic growth, there must be an investment in human capital through education for sustainable growth. Utilizing the data from twenty OECD countries, Yao et al. (2020) found an inverse association between carbon emissions and human capital from 1870 to 2014. Moreover, with the attainment of high school education, there were low carbon emissions. Yuan and Zhang (2017) performed a study on 30 manufacturing firms in China from 2003 to 2014. They suggested that human capital is a crucial source of technology innovation and knowledge spillover effects, encouraging green growth and improving environmental quality through energy-saving and technology advancement.

In comparison, few studies argue that high human capital boosts environmental deterioration. Halliru et al. (2020) documented the detrimental role of human resources on the carbon neutrality in six West African countries from 1970 to 2017. The empirical findings show that human capital significantly enhances low, middle, and high quantile carbon emissions due to the increasing trend of skilled human capital, creating the demand for establishing more educational institutes. Thus, the construction of educational universities and facilities consumes energy and emerge carbon emissions. Another cause is the lack of technical skills in human capital required in the modern process of industrial production.

Similarly Yañez et al. (2019) assessed the impact of educational activities in generating carbon emissions at Talca University of Chile and discovered that transportation is the primary determinant of producing more pollution. Thus, the students and staff use transport for mobility, creating carbon emissions within the campus. Katircioglu et al. (2020) determined the impacts of human development on the climate condition through energy usage in the Turkish Republic of Northern Cyprus. The findings highlight the significant positive impact of human education activities on climate change through more energy usage. Thus, the relationship between the concerned variables is ambiguous, requiring more empirical research to analyze their association.

2.2. Green technology and environmental sustainability

The rising environmental challenges gained attention towards adopting and using green technologies for sustainable development. Green technologies are the best tools for mitigating carbon emissions and achieving a sustainable environment with economic growth. Some prior studies claimed that clean technologies are imperative in stimulating a sustainable environment by consuming less energy. Ecological innovation differs from traditional technology because it is a process or product that saves the environment from deterioration, replaces fossil fuels with clean or renewable energy sources, and increases efficiency. Shao et al. (2021) found the negative and substantial impact of eco-innovation on carbon footprint in N-11 economies from 1980 to 2018. Using the data of G7 nations, Khan et al. (2020) explored that trade-adjusted carbon emissions are reduced through the use of environmental technologies. Razzaq et al. (2021) documented the asymmetric link between ecological innovation and consumption-based emissions in the BRICS region. The authors analyzed that ecological technology has a greater influence on reducing carbon emissions at high emissions quantiles, whereas it had no influential impact on lower emissions quantiles from 1990 to 2017. Du et al. (2019) determined the contribution of eco-innovation on pollutant emissions in seventy-six countries from 1996 to 2012. However, the countries are categorized based on income, i.e., developed and developing nations. The results concluded that clean technologies significantly reduce pollution in developed economies while they have no substantial effect in developing nations.

While some studies have discussed that eco-technologies have a negative and negligible influence on the environment because technological spillover effects change according to the economy's economic, structural, and development conditions. However, high-income countries have better economic conditions; thus, the influence of green technology is favorable for them. While low-income countries usually exist in the early development phase, and the potential positive benefits of clean innovation are not too much. The second argument is that developing countries do not have enough potential to produce or innovate green energy products due to the unavailability of skilled human resources and investment in sustainable energy (Sun et al., 2022; Yang et al., 2022). In panel data perspective, Khattak et al. (2020) conducted a study on BRICS economies and revealed that green technologies and environmental sustainability are inversely related, whereas Weina et al. (2016) explored no influence of clean technologies in mitigating carbon emissions in Italy from 1990 to 2010. For Malaysia, Yii and Geetha (2017) researched that technology has no influence on the declining carbon footprint in the long run while having an impact in the short run. Therefore, the relation between eco-innovation and ecological quality is unclear, and it is essential to explore more empirical research on the linkage between them.

2.3. Institutional quality and environment

Environmental hazards will expand in countries with ineffective environmental rules regardless of the GDP level. Hence governmental institutions are crucial for a sustainable environment (Egbetokun et al., 2020). Institutional quality is an effective determinant of environmental regulation through appropriate policies. Two categories of studies are available in the literature about the nexus between political institutions and environmental quality. Some studies claim that institutions are better positioned to improve ecological conditions' sustainability by promoting renewable energy sources and implementing strict governance regulations. Haldar and Sethi (2021) found the negative impact of institutional structure on carbon reduction in 39 nations by using the data from 1995 to 2017 and suggested that political institutions need to be improved to achieve sustainable climate agenda. Similarly, a comparative study of European, Middle East, and African countries from 1990 to 2011 (Abid, 2017) explored the good institutions can control environmental degradation without decreasing economic growth. Shahbaz et al. (2019) explored the role of institutional quality in G7 countries in that institutions protect the environment from degradation. Thus, government regulatory institutions exert a positive impact on carbon neutrality. Yasin et al. (2021) determined the influence of political institutions on carbon emissions in fifty-nine less-developed economies from 1996 to 2016. The authors found an opposite association between political institutions and pollution; thus, institutional governance plays a vital role in enhancing the sustainable environment by reducing carbon footprint in the least developing countries. Muhammad Khan (2021) examined the association between institutional quality, economic growth, and carbon emissions in 41 Asian countries from 1996 to 2015. The study found the negative impact of political institutions on carbon emissions in concerned economies. Wawrzyniak and Doryń (2020) revealed that in strong political institutions, the government's effectiveness significantly diminishes carbon pollution in emerging economies. Yasin et al. (2021) examined the effect of institutions on the ecological footprint based on EKC theory in 110 high and low-developing countries from 1996 to 2016. The findings showed an inverted U-shaped association between economic growth and ecological footprint. Moreover, the study highlights that political institutions contribute a beneficial role in enhancing environmental performance in both advanced and low-income economies. Salman et al. (2019) used the data from 1990 to 2016 and analyzed the influence of political institutions on carbon mitigation and income per capita in East Asian countries. The findings highlighted that political institution effectively reduces pollution and promote economic prosperity in selected nations.

On the darker side, some studies discussed that political institutions cause environmental deterioration by promoting economic growth. Azam et al. (2021) conducted a study to examine the impact of institutions on carbon emissions in 66 developing nations from 1991 to 2017. The study indicated that carbon emissions and political institutions are positively associated in concerned countries. In the same way, Teng et al. (2021) used the panel data of ten countries from 1985 to 2018 and discovered the positive influence of institutional quality on environmental sustainability. Obobisa et al. (2022) investigated the role of political institutions in carbon reduction in twenty-five African countries from 2000 to 2018. The study's results explored that both variables are directly related with each other; thus, the institutions of these nations are ineffective in reducing carbon emissions. Similarly, Le and Ozturk (2020) documented that in forty-seven emerging economies, due to weak government institutions and poor regulations regarding environmental protection, carbon emissions increase in these countries. Therefore, low-developing economies have a greater concentration on economic growth. Thus, high institutional quality enhances economic activities, and more trade and investment occur, increasing pollution through the scale effect. Hassan et al. (2020) found that corruption is an essential obstacle in enforcing environmental regulations, which lowers the institution's performance and

Table 1. Description of variables.

Variables	Symbol	Measurement	Data Sources
Ecological footprint	EF	Global hectares per person	GFN
Institutional Quality Index	IQ	PCA index using six indicators of institutional quality	WGI
Green Technological	GT	Environmental technologies % of all technologies	OECD
Human Capital	HC	Average years of schooling and returns to education	PWT
Gross Domestic Product	Y	Constant USD 2010 per capita	PWT

Source: Authors compilation.

quality in Pakistan. Thus, the study found that reducing carbon emissions is possible only through strict control of corruption. Therefore, the inconsistent empirical evidence of the previous studies is found, which highlights further research on the two studied variables is needed.

3. Materials and methods

3.1. Data and variable description

For empirical analyze the dynamic effects of green technology, institutional quality, and human capital on the ecological footprint in South Asian countries, the study utilizes the annual data from 1990 to 2018. For the analysis, the GDP per capita is also included as a control variable for improving the model's performance and robustness of results. Ecological footprint (EF) is a dependent variable measured as global hectares per person, and the data is sourced from Global Footprint Network (2021). The independent variables include that green technology (GT) is measured eco-technology percentage of all technologies is retrieved from OECD Statistics (2021), human capital (HC) is measured as average years of schooling and returns to education, and economic growth (Y) is measured in GDP per capita. The data for human capital and economic growth have been taken from Penn World Table (PWT).

While the Institutional Quality Index (IQ) is calculated by applying PCA, which extracts the common variations of political stability, regulatory quality, absence of violence, voice and accountability, control of corruption, and the rule of law into a single comprehensive index. The data of all six indices are retrieved from World Governance Indicators (2021). In the model, all the variables are changed into logarithmic form except the Institutional quality Index following Yuan et al. (2022). The sources, descriptions, and measurement units of data variables are mentioned in Table 1.

3.2. Theoretical framework and model description

This section describes how the explanatory variables GT, IQ, and HC affect EF in South Asian countries. The EKC theory shows a non-linear association between environmental deterioration and economic prosperity (Grossman & Krueger, 1991). Theoretically, under the EKC framework, economic development first upsurges EF through the scale effect. After reaching a certain threshold, economic growth decreases the EF through composition and technique effects. Therefore, based on EKC non-linear relationship, the variable Y is expected to be positive, i.e., $\beta_1 > 0$ and

Y^2 is predicted to be negative, that is $\beta_2 < 0$. Besides economic growth, other relevant variables may influence EF, such as green technologies, human capital, and institutional quality (Apergis & Ozturk, 2015). Following the study of Jin et al. (2021) and Ahmad et al. (2021), GT negatively affects EF. Green innovations are the production of renewable energy-related technologies, such as carbon capture methods, electric vehicles, green buildings, etc., to reduce pollution associated with energy consumption. The most recent eco-friendly and biofuel automobiles may help reduce transportation emissions. This is because eco-innovation is connected to the economic shift toward renewable energy, which can be anticipated to lower environmental adversities. Eco-innovation lowers environmental costs and aids in resource utilization. Henceforth, it is presumed that eco-innovation will have a moderating impact on EF, i.e., $\beta_3 < 0$.

Institutional quality is another crucial factor that affects EF. For the variable selection, the study follows Wang and Yan (2022) and Yuan et al. (2022), in which the institutional quality index is calculated by taking the mean of six indices. The government can control pollution and emissions levels with effective environmental policies and a strong institutional foundation. Strong institutional quality reduces transaction costs and information asymmetry, increases the market and economic efficiency, and improves the benefits of environmental protection. Political institutions also enhance the environment and economic prosperity by facilitating power distribution and high-income levels. Moreover, high political institutions control corruption, the main root cause of environmental regulation and policies (Al-Mulali & Ozturk, 2015). The direct positive impact of good institutions includes environmental legislation and policies. On the other hand, indirect impacts include regulating business, foreign direct investment inflows, businesses and investments, and financial development. Therefore, institutional structures can encourage energy efficiency is another way to generate positive effects on the environment. Finally, institutions can change the energy mix to use more renewable energy, which lowers environmental degradation. Thus, the expected sign of IQ is negative on EF, i.e., $\beta_4 < 0$.

Human capital is an essential factor that influences EF. Thus, human development by investing in education, training, and experiences contributes significantly to technological advancement. As a result, the long-term viability of human capital could be an essential tool for encouraging the adoption of green innovations through the skills and environmental knowledge it possesses. Thus, the study follows Ahmed and Wang (2019) and predicts that human capital may have an inverse impact on EF i.e., $\beta_5 < 0$.

Against the above background, the study ascertains the dynamic linkage between political governance, human capital, and ecological innovation on the environmental quality under the EKC framework. For this study, we follow the model of Ahmad et al. (2021), Wang et al. (2022), and Rani (2021) and modified it by adding the variables GT, HC, and IQ in the perspective of South Asian countries; thus the empirical model is as follow:

$$EF_{it} = f\left(Y_{it},\ Y_{it}^2,\ GT_{it},\ IQ_{it},\ HC_{it}\right) \qquad \text{Equation 1}$$

$$EF_{it} = \alpha_{it} + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 GT_{it} + \beta_4 IQ_{it} + \beta_5 HC_{it} + \varepsilon_{it} \quad \text{Equation 2}$$

Whereas in Equation (2), i refers to cross-section identities, t represents a period, ε is the error term, and coefficients of all the explanatory variables are shown as from β_1 to β_5. EF shows ecological footprint while GT is green technology, IQ is institutional quality, HC refers to human capital, Y stands for economic development, and Y^2 is a quadratic form of economic growth. Using the EKC framework, we have incorporated three additional variables, HC, GT and IQ, to analyze the impact on EF.

3.3. Econometric analysis

Cross-sectional dependency (CSD) in panel data is a significant problem that needs to be determined before starting empirical procedures. The conventional panel estimators are inconsistent because most panel data identities extensively depend on each other to the substantial growing integration and interaction within financial, political, and socio-economic structures and the unobserved common shock. As a result, neglecting CSD could have negative consequences and may distort the findings. Since simple panel unit root tests do not presume CSD in stationary analysis and may estimate biased results thus, it is essential to determine CSD. Thus, the current study applied the CSD test presented by Pesaran (2004). After applying the CSD test, the study confirms slope heterogeneity which is another relevant issue in panel data and may disturb the consistency and efficiency of slope parameters. Slope homogeneity in models is an assumption made by traditional estimators. The study used a slope heterogeneity test introduced by Hashem Pesaran and Yamagata (2008) to confirm the heterogeneity issue in the parameters before performing additional empirical estimation.

After determining the CSD and heterogeneity problem in panel data, the study employed the unit root test of cross-sectional augmented Dickey-Fuller (CADF). In addition, we also applied the cross-sectional Im Pesaran and Shin (CIPS) test to ascertain the stationarity conditions of key interest variables. Pesaran (2007) develops both tests which are more appropriate than the conventional unit root tests because they address the issues of CSD and slope heterogeneity in the model. However, traditional stationary tests do not handle the CSD and heterogeneous slopes in estimating the unit root analysis. In the panel data estimation, confirming the long-run co-integration between the variables is imperative before determining the short and long-run estimates; thus, the study applied Westerlund (2007) to examine whether the variables are co-integrated in the long run.

The presence of the long-run co-integration allows the study to use the CS-ARDL model to estimate the model's short and long-run findings. The empirical approach of CS-ARDL is presented by Chudik and Pesaran (2013), which is superior to the remaining panel data estimators (PARDL, POLS & FMOLS); these estimation techniques cannot produce consistent and reliable estimates in the existence of CSD endogeneity and slope heterogeneity of the variables. In addition, this method also considers the significant unobserved common factors in the estimation. In the last stage, the study employed an AMG estimator for robustness proposed by Eberhardt and Teal (2010).

Table 2. Cross-sectional dependence test results.

	Pesaran CSD	
Variables	Stat.	Prob.
EF	14.210***	0.000
IQ	34.854***	0.000
GT	28.420***	0.000
HC	12.409***	0.000
Y	37.125***	0.000

*** shows a significance level of 1% (Source: Authors estimation).

Table 3. Slope homogeneity test results.

Delta		Adjusted Delta	
Stat.	Prob.	Stat.	Prob.
15.646***	0.0000	16.152*	0.0000

*** shows a significance level of 1% (Source: Authors estimation).

4. Findings and discussion

4.1. Csd and slope heterogeneity test

Table 2 represents the findings of the CSD test. The test's null hypothesis is no CSD issues in variables, and the results significantly accept the alternative hypothesis of CSD, suggesting that dependent and independent variables have cross-section dependency. In the model, countries are different in economic structures, social attributes, and demographic aspects that cause the CSD in the variables. The findings of the slope homogeneity test are shown in Table 3, which indicates the significant statistical values of the delta and adjusted delta. The test's null hypothesis of no homogeneity is rejected significantly, implying that all the parameters are not homogenous for cross-sectional units.

4.2. Panel unit root tests

The study applies CIPS and CADF unit root tests that produce efficient results after confirming the panel dataset's issues related to slope heterogeneity and CSD. The outcomes of both tests are mentioned in Table 4, which affirms that the concerned variables are not co-integrated at the level while all the variables are stationary at first difference. Thus, affirmation of the stationary conditions among desired variables permits the study to examine the long-run relation through co-integration analysis.

4.3. Co-integration test

After implementing unit root tests, it is essential to determine the presence of a long-run co-integration relationship between the model's variables. Thus, the study employed the Westerlund co-integration test; the results are shown in Table 5, which exhibits that the alternative hypothesis significantly rejects the assumption of no co-integration. It implies that all model variables have a long-run association in the associated model. The coefficients of two panels (P_a and P_t) and group statistics (G_a and G_t) have significant values indicating the co-integration relationship in the variables.

Table 4. CIPS and CADF unit root test.

	CIPS		CADF	
Variables	I(0)	I(1)	I(0)	I(1)
EF	−2.043	−4.746***	−1.837	−4.043***
IQ	−1.850	−3.040***	−2.310	−3.475***
GT	−2.087	−5.152***	−2.255	−4.156***
HC	−1.418	−3.416***	−2.043	−3.850***
Y	−2.453	−5.201***	−2.630	−4.950***

*** shows a significance level of 1% (Source: Authors estimation).

Table 5. Westerlund (2007) co-integration test results.

Statistics	Values	P-values
Gt	−6.360**	0.018
Ga	−11.438***	0.000
Pt	−9.640****	0.009
Pa	−10.420****	0.000

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

Table 6. CS-ARDL test results.

	Short-run		Long-run	
Variables	Coeff.	t-value	Coeff.	t-value
IQ	−0.120*	−1.850	−0.313**	−2.630
GT	−0.085**	−2.103	−0.101**	−2.445
HC	−0.010*	−1.790	−0.072**	−2.140
Y	0.390**	2.430	1.205***	4.057
Y^2	−0.048	−1.053	−0.070**	−2.435
ECM (-1)	−0.265**	−2.308	–	–

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

4.4. Regression findings through CS-ARDL model

The study finds the long and short-run elasticities by employing the CS-ARDL estimator after determining the co-integration association in the variables. The long-run findings in Table 6 highlight that IQ is significantly and inversely associated with EF. It suggests that EF is reduced by 0.313% if a one percent increase in IQ. The findings are consistent with Haldar and Sethi (2021), who studied thirty-nine developing nations where the role of political institutions in the shape of norms and regulations in transportation and household sectors aids in diminishing carbon emissions in these countries. Thus, institutions with effective environmental policies such as carbon taxing, elimination of fossil fuels subsidies, and feed-in tariff can influence the environment. Similarly, the outcomes are identical to Mahjabeen and Marinova (2018) for D-8 economies in which the potential government institutions affect the demand for energy usage through energy efficiency. This can be done by transmitting from conventional energy to clean energy sources (geothermal, wind, biomass, solar, and tidal) with better environmental policies and technological advancements necessary for developing countries to achieve sustainable growth. Strong institutional quality reduces transaction costs and information asymmetry, increases market and economic efficiency, and improves the benefits of environmental protection. Imposing strict taxes and laws against pollution-generating sectors and business firms could change business firms' behavior to improve the environment and the collected revenue invested in promoting green technologies and eco-friendly products. Moreover, high-quality government institutes can increase expenditures on green energy projects and environment-related awareness programs that create knowledge regarding the green and clean environment and move society to low-carbon emissions.

These outcomes are against Obobisa et al. (2022), who argued that the political institutions of 25 African economies are low and weak in mitigating the adverse impacts of pollution and controlling the problem of climate change; thus, political institutions contribute to the emergence of ecological degradation. Likewise, Azam et al. (2021) claimed that institutional system positively impacts carbon emissions in 66 developing nations that heavily depend on unsustainable energy sources that generate pollution. The institutions of these countries gave more attention to industrial activities for their GDP growth and neglected environmental quality. Thus, improvements in institutional quality have led to higher carbon emissions. This is primarily because low-income nations are under more pressure to grow their economies, and improvements to institutional quality encourage more economic activity (such as the flow of FDI) as well as higher energy usage and pollutant emissions. Hassan et al. (2020) discovered that corruption in Pakistan is a significant hurdle in the regulation of reducing carbon emissions, which worsens institutional quality. The only possible solution for environmental sustainability is to control corruption.

The second variable, HC, has an inversely significant effect on EF at a 5% significance level. It shows that a one percent rise in HC reduces the EF by 0.072%; thus, HC is an essential factor in making better the environmental atmosphere. The outcome of HC is similar to Yao et al. (2020), who found that human development is a crucial determinant for a sustainable environment in twenty OECD countries. Ahmed and Wang (2019) also identified that HC is negatively related to EF in India; thus, human resources with the investment in education and research and development stimulate long-term sustainable growth through the knowledge and technology spillover effects. Skilled human capital with education gains awareness about green energy products and their importance for the environment; thus, they use ecological products in their consumption pattern and encourage renewable energy sources. Facilitating labor with the latest technology improves production with less energy-intensive consumption. Hence energy efficiency through low pollution generation; human development takes part in environmental protection. Moreover, renewable energy investment equipped human capital with technological innovation, developing new ideas for boosting green technologies. Eco-innovation saves energy through gain in efficiency and diminishes environmental pollution. The results contradict the findings of Halliru et al. (2020) for African states in which the authors evaluated that human capital and carbon footprint are directly associated because educated human capital requires more educational institutes in society. Thus, establishing universities and high schools consumes energy sources and pollution-contained materials that degrade the environment. The second reason is the unskilled labor in developing economies, thus due to the lack of technological skills and technical education required in advanced production methods of industries.

In the model, the third essential factor is GT which is inversely and significantly related to EF and indicates that a 1% increase in GT helped to overcome EF by 0.101%. The findings are identical to the study of Sun et al. (2019). They observed that clean technology is one of the practical instruments and optimal solutions required to manage energy security and environmental damage. Hence, green innovation is an effective strategy and instrument to control the adverse ecological impacts caused by human activities. The same finding is determined by Khan et al. (2020) in G7 countries, where green technology is beneficial in shifting the country to a low-carbon economy. It considerably boosts green energy supplies and ensures a sustainable environment. G7 nations can take steps to promote innovation and reduce consumption-based emissions without enforcing stringent ecological policies on businesses to enhance environmental quality.

Eco-innovation is the process that saves natural resources and the environment from degradation. Green innovation boosts long-term green growth without compromising economic growth through using renewable energy products such as solar panels, wind turbines, electric vehicles, motion sensors, recycled products, bioreactors, etc. Thus, using clean technologies consumes less energy in vital sectors of the economy, including residential, manufacturing, and transport, which cause energy efficiency. This energy efficiency reduces the cost of production in terms of energy-saving and enhances the productivity of output produced in the economy. In addition, resource efficiency has reduced the exploitation of the resources; hence fossil fuels are replaced with renewable sources that are less energy-intensive and produce an efficient output. The indirect effects of ecological innovation consist of good health, safety, and better consumer relations because they are environmental-friendly and improve financial performance. In contrast, the findings are inconsistent with Khattak et al. (2020), in which clean technologies failed to mitigate environmental pollution in BRICS countries because they have export-oriented industries. Further, their production relies heavily on non-sustainable energy sources, resulting in trade-adjusted carbon emissions.

The control variable Y is positive and significantly linked with EF; thus, a one percent increase in Y stimulates EF by 1.20%, while the Y^2 is negative and significant with EF, confirming a diminishing trend EF by 0.07% if it exceeds a certain threshold in the long run. The outcome confirms the EKC theory and shows a non-linear U-shaped curve between Y and EF for South Asian countries in the presence of relevant variables GT, IQ, and HC. The findings are aligned with the results of Sarkodie and Adams (2018) for South Africa and Le and Ozturk (2020) for 47 growing economies. Thus, initially, the increase in economic-related activities degrades the environment, but after attaining a specific or maximum level, a further rise in economic development lowers the environmental deterioration in the long run. Because at the initial stages of development, the economies are more focused on industrial production without technological assistance and consume more energy. South Asian countries primarily rely on exacerbating energy resources for the energy requirement, which releases carbon emissions. Eventually, as the income level rises, the countries will transfer more advanced clean technologies and educational skills that produce output without damaging the environment. Therefore in the long run, people emphasize

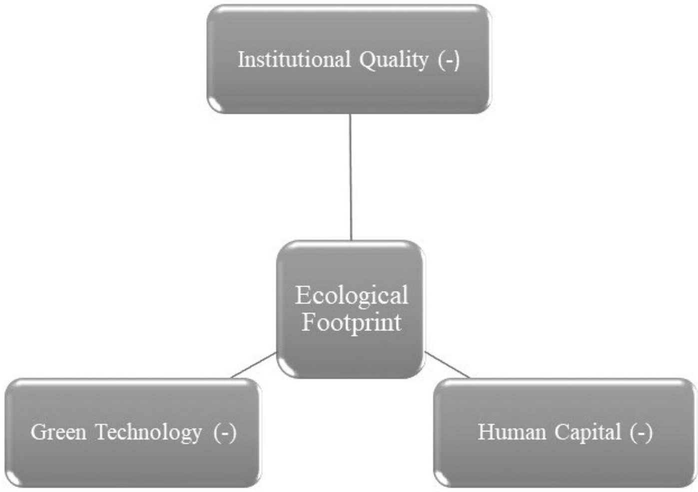

Figure 1. Outcome summary.

sustainable energy and its application for energy needs that emit fewer carbon emissions and promote inclusive green growth.

Gradually, the increasing trend of economic growth encourages financial development and globalization through which technology, knowledge, experiences, and skills are transmitted from advanced economies into these countries. This shifting produces positive spillover effects on economic and ecological conditions. Further, the transportation and energy sectors contribute to pollution in these countries. Overall findings, demonstrate that all the factors (IQ, GT & HC) are crucial for making the environment sustainable. However, the coefficient of IQ is higher than HC and GT, which indicates that the institutional quality of South Asian countries influences a greater impact on improving the environment in the long run. IQ is followed by GT, which is another magnificent factor for a sustainable environment in the shape of green energy products. The coefficient of HC is relatively small, which reveals the need for more long-term policies to enhance human resources skills through education, high living standards, and technological advancement.

Table 6 also represents the short-run estimations through the CS-ARDL model, which shows that all the variables' coefficients are identical in sign and direction as in the long run. IQ, GT, and HC decrease EF by 0.120%, 0.085%, and 0.010%, respectively. Moreover, Y enhances EF by 0.390%, and Y^2 is insignificant, suggesting the invalidity of EKC. In the short run, all the parameters of the variables have a small magnitude compared with the long-run estimates. Therefore, the factors have more profound favorable effects in the long-run period, and thus there is a need for a sustainable policy for a green and clean environment. The error correction term is significant and inversely linked with EF at a 5% significance level. In case of any deviation in the short run converges, the model adjusts with 26.5% yearly towards the steady-state equilibrium position. The flowchart represents the outcome of the relationship in Figure 1.

Table 7. Robustness check (AMG).

	AMG	
Variables	Coeff.	t-value
IQ	−0.278**	−2.495
GT	−0.132**	−2.216
HC	−0.104**	−2.329
Y	1.337***	5.364
Y^2	−0.069**	−2.145
Constant	0.420*	1.758

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

4.5. Robustness checking

In the last step of empirical analysis, the study employed the AMG estimator to ensure the robustness of prior estimates. Empirical findings (Table 7) endorse the CS-ARDL outcomes. IQ, GT, and HC decrease the EF with significant values of 0.278%, 0.132%, and 0.104%, respectively. In addition, the EKC relationship is also endorsed by the variable Y with positive coefficient values of 1.337 and Y^2 with a negative coefficient value of 0.069.

5. Conclusion and policy recommendations

South Asian nations are vulnerable to adverse environmental hazards; thus, finding their driver is imperative for sustainable policy formation. From this perspective, the current paper determines the effects of institutional quality, green innovation, and human resources on the ecological footprint in South Asian economies. The study employs the annual data from 1990 to 2018 and first examines the CSD and heterogeneous slopes among variables used in the model. After ascertaining the slope heterogeneity and CSD in the model, the study checks the stationary levels of the model's variables through the CIPS and CADF unit root tests. The results of both unit root tests affirm the stationary level of the variables at I (I). The long-run co-integration association is found among the variables by using Westerlund's test. Then, the study estimates the short and long-run relationship between the model variables by employing the CS-ARDL method. The outcomes of CS-ARDL reveal that IQ, GT, and HC reduce the EF by 0.313%, 0.101%, and 0.072%, respectively. Moreover, a significant positive value of Y with 1.205% and a significant negative value of Y^2 with 0.007% confirm the existence of a non-linear relationship and validates the EKC hypothesis. In the short run, the findings are identical to long run but smaller in magnitude. In short-run, IQ, GT, and HC decrease EF by 0.120%, 0.085%, and 0.010%, respectively. Moreover, the ECT is significant and inversely associated with EF, indicating that with any disturbance in the short run, the model will converge to a steady-state position with a 26.5% adjustment rate per annum. The robustness of these outcomes is confirmed by the AMG estimator and suggests the following implications.

The government would take effective measures and formulate the appropriate policies to improve the quality of human resources, including skills, knowledge, and healthcare. The improvement in human capital is made through providing more educational facilities, technical training, and high living standard to human capital. Governments of these countries should encourage ecological innovations by investing in research and development for green energy deployment. Also, the government should take initiatives for projects and programs related to clean and green growth that will stimulate the adoption and promotion of eco-innovation. Further, there is a collaboration with developed economies that share their technologies, skills, and experiences with these countries to develop environmental innovations and products. Asian countries should use alternatives, i.e., renewable and clean energy sources. The performance of political institutions in these countries is poor due to corruption; thus, corruption is the dominant cause in regulating environmental control. Therefore, these countries should strictly control corruption, and the government institutions strengthen with more power and authority to monitor and control the environment. Lastly, a more substantial impact of political institutions in improving environmental performance is only possible with effective environmental policies. The policies would include carbon taxes, carbon trading markets, the removal of fossil fuel subsidies, and strict regulation.

This study is limited to specific factors and time and cannot integrate regional and intra-country heterogeneous impacts. Also, there are many other drivers of ecological sustainability, such as government R&D allocations, investments, trade, and energy transition. Thus, future studies would consider other regions, countries, and derivers for more comparable outcomes.

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