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Connotation of Ecological Sustainability and the Informal Economy: Evidence from South Asia

[1]Furqan ul Haq Siddique, [2]Fauzia Ahmed, [3]Khuram Shahzad

Furqan ul Haq Siddique
IMS, University of Balochistan, Quetta.
Fauzia Ahmed
IMS, University of Balochistan, Quetta.
Khuram Shahzad
IMS, University of Balochistan, Quetta.
khurram.ims@um.uob.edu.pk

Abstract

The increasing population, growing economies, high risk of ecological degradation, climate change, and large unregistered economies are key features of South Asian economies. The degree to which these ecological effects occur varies widely and is highly dependent on the caliber of the institutions that oversee the economies. The study aims to examine the interaction of the informal economy and ecological sustainability in South Asian countries. The study applied panel-data regression analysis from 2001 to 2024, using the pooled mean-group technique for empirical testing. The findings show that the informal economy has a positive and substantial relationship with ecological sustainability. Nevertheless, the interaction between the informal economy and other macroeconomic indicators has a mixed effect on the relationship between the informal economy and ecological sustainability. The informal sector has a considerable impact on ecological degradation, which overshadows the effect of environmental policies, thereby accentuating the weakness of the established framework in major South Asian countries. South Asian countries require structural changes, primarily to introduce an incentive policy for eco-friendly production and working environments and to shift from burning fossil fuels to renewable energy sources.

Keywords: Informal Economy. Ecological Sustainability, Air Pollution (CO_2 Emissions), Macroeconomic Indicators, PMG Model, South Asian Countries.

Introduction

Ecological contamination has never been a new phenomenon, yet it remains humankind's most persistent concern and the most widespread cause of disease and death. Nevertheless, in the current era of development, urbanization, industrialization, mining, exploration, and the increased use of energy resources are posing more ecological threats to the globe. Developed and underdeveloped countries are both responsible for the ecological issues to different degrees; however, developed countries have made a greater contribution to ecological protection through increased awareness and stricter laws. Despite global attention to pollution, the impact remains significant due to profound long-term implications (Ukaogo et al., 2020; Elgin & Oztunali, 2014). It thereby prevents pollution and ecological degradation; a hygienic and healthful environment is a fundamental need for any nation's development, as it provides resources and absorbs emissions and waste.

The rise in ocean levels, greenhouse gas emissions, glacier melting, and the massive use of energy resources over the last two decades have exacerbated global warming and ecological degradation. Reducing greenhouse gas emissions to 50% by the end of 2030 and to 0% by the end of 2050 is one of the Sustainable Development Goals, as these gases account for more than 60% of global warming and climate change (Malik and Sharma, 2023; Kırşanlı, 2024). The major contributor to greenhouse gas emissions is carbon dioxide. As a result, minimizing the adverse consequences of climate change and securing sustainable energy have made mitigating or reducing CO_2 emissions a global priority (Begum et al., 2015; Huynh & Tran, 2025). The global community has experienced an unprecedented increase in CO_2 emissions over the last 7 decades. Several worldwide efforts to reduce emissions have been launched, but the bulk of carbon emissions remains substantial, necessitating research-based efforts to identify the fundamentals that drive carbon emissions (Ma et al., 2022; Devine, 2021). A sudden increase in greenhouse gas emissions is causing serious problems with the world's climate and ecological systems; countries that contribute less to greenhouse gas emissions are also affected by these issues (Tang et al., 2021; Osinubi & Simatele, 2025). One of the significant reasons for increased CO_2 emissions is rapid industrial development; almost every country aims to produce more and improve its people's standard of living through economic expansion. Economic expansion and infrastructure development involve various types of machinery that operate on different energy sources, including coal, petroleum, oil, and natural gas. All energy resources emit greenhouse gases and disturb the planet's natural environment (Malik and Sharma, 2023; Szymczyk et al., 2021). According to the Global Emission Report 2024, the negative impact on human health and a more significant effect on the atmosphere have increased since the beginning of the current century. China, India, and other emerging economies are experiencing rapid economic expansion. In 2023, the highest level of increase was recorded at 1.9%, or 994 Mt CO_2eq, compared to the previous year, 2022. China, the USA, India, the European Union, Russia, and Brazil are the most significant contributors to greenhouse gas emissions, collectively accounting for 50% of these emissions.

The scarcity of natural resources presents an opportunity for the government to utilize them to stimulate economic growth. The irresponsible use of natural resources harms the ecosystem. Fossil fuels are one of the natural resources that degrade the quality of the climate by producing greenhouse gas (Mehmood 2021). The traditional mining, agriculture, fishing, and construction sectors are now transitioning to modern machines and equipment, whereas the service sector, which is less energy- and pollution-intensive (Zhou, 2019; Nouhessèwa, 2025), is also undergoing changes. Historical trends of GHG emissions in the three most populous countries of South Asia, and their global rank in carbon emissions, are high. According to the Independent Global Health Reporting (2024), Bangladesh ranks second among the most polluted countries in the world, closely followed by Pakistan in third place and India in fifth place. According to the global ranking of carbon emissions (2025), India is in third position, emitting 2,693 million metric tons and accounting for 7% of the world's carbon, whereas Pakistan stands in 29th position and Bangladesh in 39th position. The Indian informal economy accounts for 30.1% of GDP, Pakistan's for 40%, and Bangladesh's for 43%. According to the 2025 air pollution index, Bangladesh ranks second, followed by Pakistan in third and India in fifth.

Ecological issues and greenhouse gas emissions increase as the informal economy expands, making it one of the key reasons, among many, for its growth (Baloch et al., 202; Ashena & Shahpari, 2024). The informal economy refers to the economy that operates outside of official registration with authorities, does not pay taxes, does not adhere to formal employment contracts, and lacks a formal accounting system. Underground, hidden, parallel, unregistered, shadow, grey, and irregular economies are referred to by different terms in various countries. The informal economy is almost ubiquitous worldwide, with varying proportions (Shahzad et al., 2023; Imran et al., 2024; Shahzad et al., 2025). IE is a burden on any economy and poses a threat to a country's development, as the government is unaware of informal-sector activities and taxes are not paid (Habibullah et al., 2023). It is an essential component of many economies, especially in developing countries, where few formal jobs are offered (Etim and Daramola 2020). About 2 billion people worldwide over the age of 14 belong to the informal sector, which is about 61.2 percent of the global workforce; moreover, a higher percentage share of informal employment is found in South Asia, Southeast Asia, and the Pacific region, with 87.8 percent, which is 75.2 percent of total employment (ILO 2018). The high rate of informality in many emerging and developing economies is due to differences in their GDP contributions. The GDP per capita is lower due to high rates of informality in these

regions and a large share of the population (Khambule, 2020). The high level of informal economic activity leads to insufficient environmental regulations and standards, making ecological issues more challenging to address. Companies in underdeveloped countries often exploit weak standards and regulations by utilizing polluting input materials to produce their final products (Dada et al., 2022). Countries would have slowed their economies to reduce CO2 emissions, but this slowdown has made them unwilling to progress; that is why ecological degradation is the most challenging issue to address in developing countries (Ahad and Imran 2023).

Lastly, South Asia is used in this study for the following reasons. Countries in South Asia (Bangladesh, Pakistan, and India), as well as developing and middle-income countries, have a large population. These countries rank among the highest in global air pollution and have a significant informal economy.

Literature Review

Pollution and ecological degradation are serious issues the world faces. ES is a significant concern for society, businesses, and government. Although considerable attention has been given to establishing the link between the size of the informal economy, ecological quality, and institutional standards on ecological sustainability, the relationship remains unclear. Nevertheless, the collective effects of IE, IQI, and ES have received less attention. The study aims to bridge the gap in the literature by using panel data from South Asia to investigate the impact of study parameters on air pollution (Bhattacharjee, 2024; Shahnazi et al., 2025).

A business community that operates outside of government regulations is commonly referred to as the IE (Khambule 2020). Studies on the relationship between the informal economy and ecological quality are somewhat limited, as the informal economy is large enough to have a substantial impact on ecological quality, since enterprises in the informal sector are not subject to regulations (Karaduman 2023). The IE contributes roughly one-third of global output, posing a significant challenge to environmental sustainability (Alvarado et al., 2022). Baloch et al. (2021) investigated a strong association between IE and the environment and found that IE is a key driver of air pollution. Imamoglu (2018) examines the impact of the size of informal economic activities on ecological quality in Turkey from 1970 to 2014 by combining DOLS, MOLS, and ARDL approaches. The results reveal that informal economic activities are a significant determinant of ecological quality. IE plays a role in providing jobs to people seeking to meet their necessities. Valverde et al. (2024) investigate how informal trade provides 1,636 direct jobs in Madre de Dios, which accounts for 2.1% of the total workforce. The EKC framework encompasses a substantial portion of the literature on ecological quality (Bekun et al., 2021). The economic growth and development of developing countries often rely on increased consumption of commercial energy, leading to a disregard for efficient technologies (Kais & Mbarek, 2017; Bhattacharjee, 2024; Shahnazi et al., 2025; Isik et al., 2021). The results support the EKC theory in South Asia, which posits that pollution increases with economic growth and then declines as economic expansion accelerates. Due to the large informal economy, ecological rules and standards are often low in developing economies like those in Africa, making ecological issues more burdensome. When producing products in underdeveloped nations, producers take advantage of weak standards and restrictions by utilizing more polluting raw materials (Dada et al., 2022).

Quality institutions improve the environmental quality (Khan et al., 2021); in developing and emerging markets, the unofficial economic sector accounts for 70% of employment and around one-third of GDP, where the industry is typified by a high level of income disparity, inadequate governance, low productivity, and decreased tax revenue (World Bank blog, 2019). Zhang et al. (2016) reported that bribery has a considerable negative influence in lower-emission territories but is insignificant in higher CO_2-emission regions. Additionally, corruption negatively impacts the environment, influencing per capita GDP, and has an indirect, albeit attractive, effect, in addition to its adverse direct impact on CO_2 emissions. Sah (2021) argued that in the CEMAC (Countries of the Economic and Monetary Community of Central Africa), the quality of institutions enhances ecological preservation. In most EU nations, the key factors influencing economic informality include insufficient IQI, inefficient government institutions, a complex and burdensome tax and regulatory system, and a lack of a robust legal framework, as well as widespread corruption (Shahnazi et al., 2025; Asllani & Schneider, 2024; Bhattacharjee, 2024).

Raihan and Tuspekova (2022) found that the Malaysian economy is growing positively and substantially, indicating that a percentage increase in GDP is associated with a 0.78% rise in air pollution. Ren et al. (2021) find that increases in FDI led to higher per capita carbon emissions across China's provinces, as determined by an ARDL model using panel data from 1998 to 2016. Awan and Azam (2021) investigate how technological advancements and energy use contribute to increased air pollution, while CO_2 emissions, FD, and globalization mitigate ecological degradation. Coal is a dominant energy source, and China's coal consumption significantly impacts its carbon emissions (Wei, 2024; Bhattacharjee, 2024; Shahnazi et al., 2025). Hunjra et al. (2020) find that in South Asian countries, financial development increases air pollution (CO_2 emissions) because it is often used for capital accumulation rather than technological advancement. In the process of globalization, the primary external variables that significantly affect both ecological deterioration and CO_2 emissions are foreign direct investment and trade (Islam et al., 2021). Majeed and Asghar (2021) investigated the environment of G7 and D8 countries using macroeconomic variables, including trade, energy consumption, and GDP growth, from 1980 to 2019. They employed estimated techniques such as fully

modified least squares, dynamic least squares, and heterogeneous panel estimation. The findings reveal that trade, economic growth, and energy consumption improve ecological quality in D-8 nations, whereas financial stability and trade improvements enhance ecological quality in G-7 countries. Another study examined the impact of diverse factors on the environment in 10 Asian economies from 1995 through 2018, using the common correlated effects mean group and augmented mean group methods (Wenlong et al., 2023). The study indicates that institutional quality has no significant impact on reducing greenhouse gas emissions. The finding explains the positive correlation between CO_2 emissions and institutional quality in Asian countries; moreover, trade openness has a positive effect on greenhouse gas emissions in both the short-run and long-run. The migration of the workforce from rural to urban areas increases energy demand, leading to CO_2 emissions and contributing to air pollution (Khan & Hou, 2021). Camara (2022) investigated the impact of the informal economy on economic growth and found that industrialization and urbanization tend to enhance economic growth but also increase CO_2 emissions in 14 countries of the Economic Community of West African States.

Imran et al. (2022) examine energy use and the impact of environmental sustainability in QUAD economies (India, Japan, the US, and Australia) from 1991 to 2021, using the moment quartile regression technique, and find that renewable energy production and technology use enhance environmental sustainability. The use of non-renewable energy resources exacerbates the situation. Long-run forecast results indicate that CO_2 emissions (air pollution) in the thirty International Energy Agency member countries have an opposite relationship with ecological sustainability, waste, and renewable energy sources. The governments of these countries can enhance environmental quality by using energy sources to reduce CO_2 emissions. (Khan & Hou, 2021). Ren et al. (2021) explore the positive relationship between per capita energy consumption and per capita carbon emissions. Ecological quality improves with rising economic growth and renewable energy consumption in emerging economies, whereas consumption of non-renewable energy degrades environmental quality (Sultana et al., 2022; Bhattacharjee, 2024; Shahnazi et al., 2025). The above literature provides the importance of regarding emissions of greenhouse gases, the informal economy, and institutional quality. The relationships between ecological quality and pollution, as well as ecological quality and the informal economy, have been adequately explored in the existing literature. While reviewing the literature, the study primarily focuses on the relationships among ecological quality, economic growth, and the informal economy. Therefore, the study's primary objective is to examine how the scale of the unregistered economy affects ecological sustainability, and its secondary objective is to examine the role institutions play in the relationship between the informal sector and ecological sustainability.

Model:

The paper investigates the impacts of the informal economy on ecological sustainability. This study attempts to measure the empirical model for South Asia (Bangladesh, Pakistan, and India). According to the theoretical framework, the following empirical model is formulated:

$$\mathrm{AP}_{it} = f\left(IQ\mathrm{I}_{it}, GDP_{it}, IE_{it}, FD_{it}, UR_{it}, T\mathrm{O}_{it}, E\mathrm{C}_{it}, FDI_{it}, \mathrm{U}_{it}\right) \quad (1)$$

EU = Energy Usage

FD = Financial Development Index

FDI = Foreign Direct Investment

URB = Urbanization

TOP = Trade openness

$$ln\mathrm{AP}_{it} = \alpha_{it} + \beta_1 lnIE_{it} + \beta_2 IQ\mathrm{I}_{it} + \beta_3 (IE * IQ\mathrm{I})_{it} + \beta_4 lnGDP_{it} + \beta_4 FDIX_{it} + \beta_5 FDI_{it} + \beta_6 E\mathrm{U}_{it} + \beta_7 UR_{it} + \beta_8 T\mathrm{O}_{it} + \in_{it} \text{----------} 2$$

Table 1

Variable	***Measure***		***Source***
Air Pollution	*CO2*	*AP*	*World Development Indicator.*
Informal Economy	*Size as % of GDP*	*IE*	*World Development Indicator.*
Institutional Quality	*IQ index*	*IQI*	*World Development Indicator.*
Gross Domestic Product	*Real GDP constant 2015*	*GDP*	*World Development Indicator.*
Foreign Direct Investment	*Net inflow % of GDP*	*FDI*	*World Development Indicator.*
Urbanization	*Annual % increase in urban population*	*UR*	*World Development Indicator.*
Trade Volume	*% of GDP*	*TO*	*World Development Indicator.*
Energy Consumption	*KWh/individual*	*EC*	*World Development Indicator.*

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Financial Development	*FD Index*	*FD*	*World Development Indicator.*

Source: *World Development Indicator & Author calculation*

This study aims to examine the impact of the informal sector on ecological sustainability in three populous countries. In addition, the study incorporates the interaction of IQI in driving the relationship between the informal economy and ecological sustainability. The data is extracted from 2001 to 2024 in South Asia (Bangladesh, Pakistan, and India). All of these are developing economies and aim to control their weather conditions through development. The variables measured include air pollution (CO_2 emissions), size of the informal economy, energy consumption, gross domestic product, urban population, foreign direct investment, financial development, and trade. The components that comprise the Institution Quality Index are control of corruption, rule of law, government effectiveness, political stability and absence of violence/terrorism, regulatory quality, and voice and accountability. This data has been obtained from World Development Indicators (WDI) published by the World Bank, except for Financial Development, which is extracted from the International Monetary Fund (IMF). A detailed description of the variables, the proxy used, and the data sources is presented in Table 1.

Methodology and Model

The study employed a quantitative research design, utilizing panel data from 2001 to 2024 for the three most populous countries in South Asia. Countries with low populations and small economies were excluded from the study. This study uses a combination of many empirical tests, including the cross-sectional dependence test CD, the stationary test, and the pooled mean group technique. The cross-sectional dependence test (CD test) is a frequently used tool for panel unit root testing in the presence of heterogeneity, as cross-sectional dependence can yield erroneous results. Pesaran (2007) employs the cross-sectional augmented Im, Pesaran, and Shin (CIPS) panel unit root test to assess whether cross-sectional dependence exists. This unit root test is particularly suitable for scientific applications, as it yields reliable results even when cross-sectional effects are present (Ghosh 2022).

$$\boldsymbol{Y_{it}} = \boldsymbol{\alpha_i} + \boldsymbol{\beta_i X_{it}} + \in_{it}$$

Where $\boldsymbol{i}$ shows the cross-sectional and **t** symbolizes the timeframe for the investigation. The mathematical calculation of this test is as follows:

The correlation of residuals, or least-squares estimation, is represented by μ2, the component of the LM Pesaran scales test.

$$\boldsymbol{LM = T} = \sum_{M=1}^{n-1} \sum_{l=M-1}^{n} u2\ ml\ x2 \quad n\,(n-1)/\,2$$

Cross-sectional dependence is the alternative hypothesis, while cross-sectional independence is the null hypothesis for the test.

Various unit root tests are conducted to determine the stationarity of the variables, as they must be stationary at the level or in first differences to establish a long-run relationship using the panel cointegration estimation technique (pooled mean group). The dynamic panel version of the ARDL model is employed as the estimating approach for panel data, maintaining the panel model with high N and T (Pesaran, Shin, & Smith, 1999; Levin, Lin, & Chu, 2002). This study employs the pooled mean group estimation approach, as described by Pesaran, Shin, and Smith (1999), which has been further developed by Pesaran et al. (1999). The pooled means group is an intermediate estimator that requires homogeneity in the long-run coefficients but allows for group differences in intercept, short-run coefficients, and error term. When all of the model's variables are either 0 or 1 series or a combination of both, and have different orders of integration, PMG can be used for them. The next step is to apply the stationarity test to panel data. If the panel data reveal a cross-sectional pattern, the first-generation unit root is inconsistent; hence, the study uses the second-generation unit root test. It is a standard practice to perform a unit root test to determine whether a series is stationary (using a panel ARDL) before applying econometric techniques.

Empirical analysis employs a Panel Autoregressive Distributed Lag (ARDL) model, estimated using the Pooled Mean Group (PMG) estimator developed by Pesaran, Shin, and Smith (1999). This approach is selected over other common panel estimators (such as Mean Group (MG) or Dynamic Fixed Effects (DFE)) due to its suitability for our research question and data structure. Investigating the existence of a stable, long-run equilibrium relationship between the variables presented in Table 1 (Frankel & Romer, 1999; Levine, 2005; Blackburne & Frank, 2007). Assuming all countries have identical short-run and long-run coefficients is overly restrictive and ignores unique institutional, political, and cyclical factors. Estimating a separate model for each country and then averaging the coefficients (the MG approach) is an inefficient method. It may fail to identify a common long-run relationship if it exists, especially in panels with a relatively short time dimension (T) (Nickell, 1981). Whereas the PMG estimator provides an optimal balance, it restricts long-run coefficients to be homogeneous across all panels and allows short-run coefficients for speed of adjustment and error variance. The ARDL model is reparameterized into an error-correction form, which serves as the basis for PMG estimation (Pesaran, 2004; Pesaran et al., 1999).

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Results and Discussions

Table 2 presents the descriptive statistics; all variables have positive means. Table 2 also provides the lowest and highest values, as well as the data set's range. Descriptive statistics also provide the lowest and highest values, the median (all positive), and the standard deviation of the data set.

Table 2: ***Descriptive Statistics***

Variable	Mean	Median	Max	Min	Std. D
LNAP	12.178	11.853	14.715	9.731	1.538
LNIE	3.404	3.548	3.606	2.995	0.234
IQI	0.459	0.278	0.997	0.000	0.329
LNGDPG	26.533	26.216	28.620	24.956	1.065
FDI	1.090	0.853	3.621	0.029	0.724
FDIX	0.308	0.278	0.509	0.138	0.110
EC	3325.385	3406.496	6731.805	935.981	1495.259
TO	34.676	32.209	55.794	21.460	8.965
UR	3.013	2.819	4.560	1.780	0.648

Table 3 presents the cross-sectional dependence test results in the bottom panel. The probability value from the estimation is 0.261, indicating that the model under consideration does not exhibit cross-sectional dependence. A unit root test was employed to determine the sequence of integration for the variables in the model (Pesaran-Shin, 2003; Levin, Lin, & Chu, 2002). There is mixed integration across all variables; the results of the unit root test are presented in Table 3. Some variables in the Table are stationary at the level, such as IQI, IQIIE, and lnGDP, as indicated by the Pesaran test. All the other variables are stationary at the first difference. The results obtained from the panel ARDL are presented in Table 4. In the first model, the results indicate a positive and statistically significant relationship between the informal economy and air pollution. The coefficient for the informal economy is 0.353, implying that a 1% increase in the informal economy results in a 0.353% increase in air pollution (CO_2 emissions) in South Asian states. The primary reason for the high levels of greenhouse gases in South Asia is the significant contribution of small businesses and enterprises, which emit high levels of greenhouse gases due to increased energy consumption.

This informal business primarily relies on outdated technologies and polluting fuels and has an improper waste-disposal system and inadequate recycling practices, which further contribute to these emissions. Similar to Model 2, the findings indicate a positive and substantial relationship between the informal economy and air pollution, with a coefficient of 0.711, suggesting that a 1% increase in the informal economy corresponds to a 0.711% increase in air pollution. The findings support those reported by Imamoglu (2018) and Dada et al. (2022), who noted that an expansion of the informal economy is associated with greater ecological degradation. The informal sector employs a large share of the workforce; however, these enterprises often use outdated, inefficient equipment, which increases ecological pollution.

Table No 3: ***Unit root test and Cross-sectional Dependence Test***

Variables	Im-Pesaran-Shin Unit Root Test		Levin Lin, and Chu Unit Root Test	
	At level	First Diff	At Level	First Diff
LNAP	0.955	0.012	0.35	0.355
LNIE	0.996	0.0000***	0.958	0.003***
IQI	0.008***	0.0000***	0.009***	0.002***
LNIQI	0.016***	0.0000***	0.009***	0.002***
LNGDP	0.014**	0.0000***	0.071	0.000***
FDI	0.15	0.0000***	0.242	0.001***
FDIX	0.169	0.0000***	0.342	0.000***
EC	1.000	0.0467**	0.9898	0.2355
TO	0.192	0.0172	0.1432	0.0075**

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Cross-sectional Dependence Test			
Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	5.692	3.000	0.112
Pesaran Scaled LM	1.221		0.271
Pesaran CD	-1.321		0.261

*P-values indicating significance at the 1%, 5%, and 10% levels, respectively, are shown in parentheses (***, **, and *).*

Furthermore, the informal sector lacks access to most financial services. The lack of financial facilities for the informal sector reduces the prospects for investing in research and development and for implementing ecologically friendly technologies that benefit the environment (Elgin & Oztunali, 2014; Kırşanlı, 2024; Huynh & Tran, 2025; Devine, 2021; Osinubi & Simatele, 2025).

Table 4: ***Pool Mean Group Regression Results***

Variable	Model 1	Model 2 (with interaction term)
LNIE	0.353 (0.030) **	0.711 (0.0000) ***
IQI	-0.428 (0.0000) ***	-0.151 (0.016) **
LNGDP	-0.005 (0.3325)	-0.005 (0.431)
EC	0.0001 (0.0000) ***	0.0001 (0.0000) ***
FDI	0.003 (0.0000)***	0.030 (0.0000) ***
FDIX	-0.191 (0.031)***	-0.341 (0.0000) ***
UR	-0.191 (0.0000)***	-0.912 (0.0000)***
TO	-0.002 (0.015)**	-0.002 (0.002)***
LNIE*IQI		0.019 (0.0000)***

*P-values indicating significance at the 1%, 5%, and 10% levels, respectively, are shown in parentheses (***, **, and *).*

IQI is a key factor in improving ecological quality; weak institutional structures damage the ecology, whereas strong institutional quality enhances it (Hunjra 2020). Model 1 shows a negative, significant relationship between IQI and AP. The coefficient for IQI is -0.428, indicating that a 1% increase in IQI results in a 0.428% decrease in AP. The primary reason for the significant, negative relationship between IQI and AP is the lack of effective ecological regulations, poorly designed policies, inadequate enforcement, bribery and corruption, undermining of ecological initiatives, insufficient accountability and transparency, and inadequate monitoring. Rapid industrialization, often without adequate control, in developing countries, combined with fossil fuel subsidies, contributes to increased CO_2 emissions in these regions. Unplanned urbanization is also a significant factor in these emissions. Similar to Model 1, the results indicate a substantial yet adverse relationship between institutional quality and air pollution. The coefficient of institutional quality is -0.15. This implies that a 1% increase in institutional quality led to a -0.15% reduction in carbon emissions (Zakaria & Babi, 2019).

The results further indicate that Model 1 shows a negative, insignificant association between GDP and ecological sustainability. The constant in the GDP equation is -0.005, implying that a 1% increase in a country's GDP is associated with a 0.005% reduction in CO_2 emissions. The primary reason for the negative and insignificant relationship between CO_2 emissions and GDP is industrialization, which increases energy demand and waste generation. Globalization and trade also increase as a country's industrial development advances. The low adoption of energy-efficient technologies, combined with the high number of vehicles on the road, ultimately results in high emissions. However, in Model 2, the data demonstrate a positive but insignificant association between GDP and CO_2 emissions. The GDP coefficient is 0.005. It suggests that a 1% increase in GDP is associated with a 0.005% rise in air pollution (Jin et al., 2022; Abbasi & Adebayo, 2021). It was reported that increased carbon emissions cause ecological pollution and have a significant negative impact on economic development, thereby hindering the sustainable development of the economy and global society. The use of energy and foreign direct investment are highly significant and positively correlated with CO_2 emissions in both models (Seker et al., 2015).

An investigation into the impact of foreign direct investment on ecological sustainability in Turkey reveals that the long-run coefficient of the ARDL model is positive but small. Osobajo et al. (2020) examine the association between energy usage and GDP on air pollution, using data from 70 countries between 1994 and 2013. The pooled OLS regression results indicate that both energy consumption and economic growth are positively and significantly associated with CO_2 emissions. Aluko (2020) has demonstrated

that financial development is a key determinant of ecological quality. Shoaib et al. (2020) employ the pooled-mean-group panel ARDL methodology to examine the relationship between financial development and air pollution across the G8 and D8 countries from 1999 to 2013. Their findings confirm that financial development exerts a significant and positive influence on ecological sustainability at the 1% level in both panel models for the long-run relationship. Nevertheless, in Model 1 of the study, a substantial but adverse association is found between ecological sustainability and foreign direct investment, with a coefficient of -0.186, indicating that a 1% increase in foreign direct investment is associated with a 0.191% decrease in ecological sustainability.

However, in Model 2, the results indicate a positive but substantial association between foreign direct investment and ecological degradation. The coefficient for foreign direct investment is -0.34, indicating that a 1% increase in foreign direct investment is associated with a 0.34% decrease in ecological sustainability. The conclusion aligns with the findings of Aluko (2020) and Hunjra et al. (2020), who indicate that financial development is negatively correlated with CO_2 emissions, suggesting that financial development contributes to improved ecological quality. Urbanization and trade openness are control variables in the model. In Model 1, urbanization is negatively and significantly associated with CO_2 emissions. Qayyum et al. (2021) examine the impact of urbanization and the informal economy on ecological footprints in South Asia, finding that both contribute to environmental degradation. During the short run, urbanization has a beneficial influence on ecological footprints in Bangladesh, Nepal, Pakistan, and Sri Lanka, but not in India. In contrast, the informal economy exacerbates ecological degradation in all countries except Bangladesh. Trade has a constructive and substantial relationship with air pollution.

The interaction term between the informal economy and the institutional quality index exhibits a constructive and substantial association with environmental damage in South Asia. A 1% enhancement in the interaction term results in a 0.019% increase in ecological depletion. The institutional quality enhances the substantive association between the informal economy and ecological sustainability. The informal economy has a positive impact on institutional quality. The impact of the informal economy is so significant that it even outweighs the adverse effects of poor institutional quality and air pollution. It may be due to weak intuitions. Corruption, implementation of law, government policies, political conditions, low violence, low terrorism, regulatory quality, and voice and accountability are weak in South Asia. Enforcing environmental standards and encouraging sustainable practices are two ways that strong, transparent, and responsible institutions can mitigate the ecological impact of the informal economy. On the other hand, inadequate institutions exacerbate these problems and cause ecological damage (Nouhessèwa, 2025; Ashena & Shahpari, 2024; Bhattacharjee, 2024; Shahnazi et al., 2025).

Conclusion and Policy Implications

Enhancing ecological quality is an important consideration in the UN's sustainable development strategy. In this paper, we focus on the informal economy, ecological sustainability, and the role of institutional quality across a panel of three South Asian countries from 2001 to 2024. In general, we find that the informal economy degrades the environment, and institutional quality strengthens the connection between the informal economy and air pollution. These empirical findings lead to several key conclusions with important policy implications for South Asia and other countries with political and economic systems similar to those studied. The study uses data from the World Bank and the International Monetary Fund from 2001 to 2024 to examine the impact of the informal economy on the environment in South Asia. Enhancing the quality of institutions is crucial for achieving more sustainable ecological outcomes. Strengthening the institutional framework involves improving the government's structural capacity and formulating and implementing effective ecological policies, thereby enhancing regulatory quality and ensuring robust enforcement mechanisms. The study recommended that countries in South Asia increase their use of renewable energy to reduce carbon emissions. Climate change should be integrated into the regional sector plans of South Asian countries, and civil society organizations should play a more active role in raising public awareness and encouraging the government to be more sensitive to the impact of the informal economy on air pollution. The government should develop laws that encourage firms to transition from the informal to the formal sector.

Additionally, it should implement information programs targeting informal workers and enterprises, informing them about the ecological impact of their operations and providing access to low-cost pollution-control technologies. Provide microfinance and grants to support ecologically sustainable projects within the informal sector, as financial incentives encourage the adoption of green practices. Additionally, offer tax rebates and other incentives to informal sector businesses that demonstrate a commitment to ecological sustainability. Nonetheless, the study's findings are not without limits. The study employed a pooled mean-group estimation procedure with some restrictions; however, alternative panel-data approaches based on nonlinear models with additional variables may yield different results. As a result, we propose that future research examine the effects of research and development, as well as renewable energy financing, on reducing air pollution. Additionally, including more countries in future research would provide a comprehensive understanding of the context, ensuring robustness and informing better policy development and intervention.

The structured policy mechanisms for South Asian countries have to be organized around a strategic approach, including, first, the mechanism of tiered registration and tax payments for informal economic units. Secondly, to provide eco-friendly registration, including adherence to environmental standards. Thirdly, the government and financial

sector must provide green microfinance and grants involving donors and banks, such as loans for electric rickshaws, grants for waste pickers to purchase safety gear and tricycles, or subsidies for informal repair shops to upgrade to energy-efficient tools. Fourthly, policymakers should create dedicated green spaces and resource centers to replace informal settlements and markets. Lastly, there must be green skills training and capacity-building training through vocational centers.

As the study concluded that the informal sector decreases ecological sustainability, it moves beyond the conventional view of the informal economy as solely an environmental liability or governance failure. The novel contribution is the framework for the synergistic formalization as a policy approach. Therefore, the key is to ensure that the path of formality is accompanied by green incentives, resulting in a triple win: improved livelihoods for workers, increased government revenue, and greater ecological sustainability.

Future studies should focus on the immediate evaluation of policy mechanisms for green finance and the formalization of the informal economy in South Asia. Future research should employ randomized controlled trials (RCTs) or quasi-experimental methods to measure the causal impact of formalization on both formalization rates and specific environmental indicators, such as waste diversion and air pollution. Detailed studies of each sector are necessary at this time, following the results of the current study, to enable the evaluation of each sector's analysis. What technology is the world using to reduce air pollution, and what is the position of South Asia?

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