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Ecological Consequences of Energy Poverty in South Asia

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Abstract
Ecological imbalances are caused by limited access to clean energy. The continuous use of traditional energy sources for economic activities has deteriorated the environmental conditions. Addressing the energy poverty, need a varied approach that combines improved access to clean and affordable energy with sustainable resource management practices. This study seeks to investigate the effects of energy poverty on environmental quality in South Asian countries used panel data spanning 2000 to 2021. For analysis, the CIPS second-generation panel unit root test was used to determine the existence of cross-sectional dependence, while the Pool Mean Group (PMG) was applied as a result. In both periods, energy poverty is negatively linked with the ecological footprint, and GDPpc is positively related to the ecological footprint. In the context of South Asia, policies should address both issues by investing in renewable energy infrastructure development.
Keywords: Ecological footprint, Energy Poverty, Economic Growth, South Asia, Sustainability

1. Introduction
Energy poverty traces back to the UK's fuel rights movement in the early 1940s (Zhou et al., 2022). In 1990, the ecological footprint was introduced to assess the environmental impact of human activities (Nautiyal & Goel, 2021). The ecological footprint measures the gap between how much we are consuming from nature compared to how much nature can replenish. Recent records reveal a significant increase in this gap and the production and consumption of energy generate environmental problems. Greenhouse gas emissions rise in the atmosphere with human activities. Three billion people are using traditional methods for cooking in developing countries, which raises CO_2 emissions in the atmosphere (Espinosa & Koh 2024; Kousar et al., 2020). In 2022, global primary energy consumption expanded, but the consumption of gas declined by 3% due to the energy crisis and Ukraine war (UNEP, 2023).
The negative consequences are that biomass burning releases harmful pollutants such as carbon dioxide (CO_2), carbon monoxide, and organic carbon (OC), affecting air quality, visibility, human health, and climate on a global scale (Chen et al., 2018). The World Health Organization estimates that around 3.2 million individuals die annually due to indoor air pollution, stemming from incomplete combustion of solid fuels (WHO, 2023). Around 660 million people still have no access to electricity, while 2 million people use polluting cooking fuels and technologies (UNDP, 2023). In the past few decades, South Asia has experienced significant economic growth due to industrialization and the development of the financial sector. The GDP of the region increased from $190.7 billion to $3,241.9 billion, at an average rate of 4.92% per year. However, South Asia is still vulnerable to environmental hazards that need immediate attention (Rahman et al., 2024). In South Asia, climate change and human activities are causing shifts in water systems, food production challenges, and pollution. To reach SDG-7, South Asian nations must use a mix of energy sources (Katekar & Deshmukh, 2021).
In Pakistan, 54.6 percent of households face energy poverty. Fossil fuel is the current energy system in Pakistan. In rural India, 70 percent of the population has no access to clean energy, while urban areas of India consume advanced energy resources (Batool et al., 2023; Yawale et al., 2023). Bangladesh is a developing country, and 18 percent of the population in rural areas of Bangladesh had no access to electricity in 2019. Energy poverty in Bangladesh is a more serious problem than financial poverty. Urbanization, economic expansion, population growth, and industrialization raise the demand for energy in Bangladesh (Hosan et al., 2023). According to Lohani et al. (2023), Nepal mainly relies on traditional biomass for 66.54% of its energy needs, and fossil fuels contribute 27.24%. Most of the population in Nepal continuously faces energy poverty. The energy supply in Sri Lanka is derived 33.2 percent from biomass, 11.5 percent from coal, 7.5 percent from hydropower, and 3.9 percent from renewable energy as primary energy sources (Illankoon et al., 2022). This study investigates the diverse ecological consequences of energy poverty in South Asia. This study helps to understand how energy poverty contributes to environmental degradation. Economic growth is given priority in South Asian countries' macroeconomic policies, with environmental protection receiving little attention (Xue et al., 2021). In developing nations, increased foreign direct investment exacerbates environmental damages. To save the environment and cut CO_2 emissions, we must switch to renewable energy (Wahyudi et al., 2023). The primary objective of this study is to explore the effects of energy poverty on the ecological footprint in South Asian countries. Energy poverty in South Asia poses a dual challenge that hinders both development and environmental well-being. energy poverty is a significant obstacle to sustainable growth and coordinates with UNDP sustainability goals.
The empirical literature discussed the aspect of energy poverty framework particularly in developing countries.

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Some significant studies focused on energy poverty and economic development (Amin et al., 2020; Kousar et al., 2020; Ann & Mirza, 2020; Udemba, 2020; Danish et al., 2020; Majeed et al., 2021; Doganalp et al., 2021; Pan et al., 2021; Oryani et al., 2022; Li et al., 2023; Zaman et al., 2023; Zhang et al., 2023; Magazzino, 2024). The non-renewable energy effect ecological footprint (Sharif et al., 2020; Pata et al., 2021; Mehmood, 2021; Ulucak et al., 2021; Garba & Bellingham, 2021; Raghutla et al., 2022; Khan et al., 2022; Murshed et al., 2022; Kumar & Rathore, 2023; Arnaut & Dada, 2023; Amin et al., 2023; Roy, 2024). Furthermore, globalization significantly positively related to ecological footprint (Sabir & Gorus, 2019; Kirikkaleli et al., 2020; Langnel & Amegavi, 2020; Usman et al., 2020; Apaydin et al., 2021; Salari et al., 2021; Rehman et al., 2021; Amin, 2023; Villanthenkodath & Pal, 2023; Tran et al., 2024; Carfora & Scandurra, 2024), energy poverty effects carbon emissions (Zhao et al., 2021; Bruckner et al., 2022; Yahong et al., 2022; Li et al., 2023; Hernandez & Molina, 2023; Galvin, 2024; Zhao et al., 2024), and in Sub-Saharan African countries analyze that energy poverty effect environmental degradation (Majeed, 2021; Zhao, 2021; Nathaniel & Adeleye 2021; Mujtaba et al., 2022; Dimnwobi et al., 2023; Byaro et al., 2023; Opoku et al., 2024; Rao, 2024). In all above literature studies focused on energy poverty various accepts. The novelty of our study significantly contributes to investigates the ecological consequences of energy poverty in five South Asian countries (Bangladesh, India, Nepal, Pakistan, and Sri Lanka) by used Pool Mean Group (PMG) approach to fill the research gap.

2. Material and Methods

This study uses data from five South Asian countries from 2000 to 2021. Different methods were employed to examine the link between variables. First of all, to deal with panel data from multiple countries, the cross-sectional dependency test was conducted to ensure any correlation between the countries. To check panel data stationarity of variables across times and countries, we used CIPS 2nd generation panel unit root test. The CIPS results show mixed order of integration. After that PMG model has been selected based on Hausman test and its corresponding probability results. The PMG test provides both long run relationship and short run dynamics of the variables used in this analysis. This study employs secondary data sourced from World Bank Statistical Review of World Energy, and Global Footprint Network Database**.** This study used panel data on ecological footprint, energy poverty, foreign direct investment, GDP per capita growth, and financial development in five South Asian countries like Bangladesh, India, Nepal, Pakistan, and Sri Lanka from the period of 2000 to 2021. Energy poverty is an index constructed from four dimensions of energy poverty. Two dimensions are related to access to clean fuel and technologies and access to electricity. Other two dimensions are related to renewables energy consumption and share of electricity from renewables. PCA used to construct index of these four-energy poverty dimension. High value of energy poverty index indicates low rate of energy poverty. Low energy poverty index value indicates high rate of energy poverty.

Table 1: Variables Description and Measurement

Symbols	Variables	Measurement
EP1	Energy poverty 1	Access to clean fuels and technologies for cooking (% of population)
EP2	Energy poverty 2	Access to electricity (% of population)
EP3	Energy poverty 3	Share of electricity production from renewables (% population)
EP4	Energy poverty 4	Renewable energy consumption (% of total final energy consumption)
EP	Energy Poverty Index	Utilizing data from EP1-EP4 through PCA
ECFO	Ecological Footprint	Global hectares per person
FDI	Foreign direct investment	Foreign direct investment, net inflow (% GDP)
GDP_{pc}	Gross Domestic Product Per Capita Purchasing Power Parity	GDP per capita, PPP (constant 2017 international $)
FD	Financial Development	Domestic credit to private sector (% of GDP)

Note: Data derived from World Development Indictors, Statistical Review of World, and Global Footprint Network Database

The main objective of this study is to examine how energy poverty effects the ecological footprint. In this model ecological footprint serving as dependent variable and energy poverty index as a independent variable, while FDI, and Gross Domestic Product Per capita Purchasing Power Parity (GDP_{pc} PPP) as a control variable. Functional form express as:

$$\mathbf{ECFO_{it} = f(EP_{it}, FDI_{it}, GDP_{it}, FD_{it})} \quad (1)$$

In equation 1, ECFO is ‘Ecological footprint’, shows environmental quality. EP show the index of energy poverty. The econometric model log form expressed as:

$$\mathbf{ECFO_{it} = \beta_0 + \beta_1 EP_{it} + \beta_2 FDI_{it} + \beta_3 GDPpc_{it} + \beta_4 FD_{it} + \mu_{it}} \quad (2)$$

In equation 2. U is disturbance term, i shows country (i = 1…n) and t is time. $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ are long run coefficients. GDP shows Gross Domestic Product Per capita Purchasing Power Parity, FDI is foreign direct investment, and FD shows financial development.

Table 2: Descriptive Statistics

Variable	Mean	Standard Deviation	Min	Max
ECFO	0.83	0.20	0.44	1.25
EP	2.75	32.2	-44.9	84.3
FDI	0.98	0.70	-0.09	3.62
GDP_{pc}	5.00	2.91	2.02	13.7
FD	37.0	16.2	13.8	103.6

Note: Author's calculations

In Table 2 the ECFO is a dependent variable, which has an average value of 0.83gha. The minimum value, 0.44, shows the lowest value of ecological footprint for Bangladesh in 2000. Bangladesh's industrial sector was less developed in 2000 (at the beginning of the sample period), resulting in low environmental impacts as compared to other South Asian countries. Industrialization significantly contributes to environmental pollution through resource exploitation, waste generation, and emissions. The maximum value, 1.25, shows that Sri Lanka has a relatively high ecological footprint in 2017 due to urbanization, industrialization, and high levels of consumption. The minimum value of the EP index value, -44.9, indicates the high energy poverty level of India in 2020. On the other hand, the maximum energy poverty index value, 84.3, shows low energy poverty levels for Nepal in 2001. The energy poverty average value, 2.75, is closer to the minimum index value of India in 2020 and far from the maximum index value of Nepal in 2001, which indicates that in our sample the ratio of observations representing high energy poverty is more than those representing low energy poverty.

Foreign Direct Investment (FDI) with a mean value of 0.98, indicates that there is a positive net inflow. The maximum value, 3.62, indicated significant foreign direct investment for India in 2008, while the minimum value -0.09, which indicates more capital leaving the economy than entering it, which means low investment in renewable energy sources lead to increase resource exploitation that caused a high ecological footprint in Nepal in 2002.

The mean value of GDP_{pc} 5.00, shows the average economic status across the countries. Nepal with a minimum GDP_{pc} value of 2.02, in 2000 (at the beginning of the sample period) shows that low level of industrial activity, low energy consumption, and overall resources. Low GDP_{pc} leads to a low ecological footprint in Nepal often faces environmental challenges related to deforestation, urbanization and financial constraints. On the other hand, higher GDP_{pc} indicates the high level of consumption, industrialization, and urbanization. In 2018, Sri Lanka's high GDP_{pc} value 13.7, indicates a high level of ecological footprint due to increase in economic activities, an increase in the demand for transportation services leads to high emissions.

Financial development (FD) with a mean value of 37.0, indicates that a high level of FD promotes investment and access to credit. Economic activity increases, leading to high consumption and industrialization that increase ecological footprint. The unstable financial system of a country might prioritize short-term gains over long- term sustainability resulting high ecological footprint. In 2017, Pakistan's FD minimum value 13.8, shows that due to limited financial resources, it might not invest in renewable energy and green infrastructure, resulting high level of ecological footprint because countries rely on traditional sources of energy. Nepal's highest value of 103.6 in 2021 indicates that Nepal invests in eco-friendly projects and uses clean technology that helps to reduce its ecological footprint.

Table 3: Cross Sectional Dependence Test Results

Variables	BP LM	Pesaran scaled LM	Bias- correlated scaled LM	Pesaran CD
ECFO	68.2^{***} (0.00)	13.0^{***} (0.00)	12.9^{***} (0.00)	2.39^{**} (0.01)
EP	199.7^{***} (0.00)	42.4^{***} (0.00)	42.3^{***} (0.00)	14.1^{***} (0.00)
FDI	27.7^{***} (0.00)	3.95^{***} (0.00)	3.84^{***} (0.00)	1.79^{*} (0.07)
GDP_{pc}	211.4^{***} (0.00)	45.0^{***} (0.00)	44.9^{***} (0.00)	14.5^{***} (0.00)
FD	71.80^{***} (0.00)	13.8^{***} (0.00)	13.7^{***} (0.00)	3.39^{***} (0.00)

Note: In this table * represent the rejection of null hypothesis at 10% level of significance, ** represent 5% level of significance, and *** represent 1% level of significance.

Table 3 results show that the Pesaran CSD test null hypothesis states that there is no cross-sectional dependency so, based on significance levels 1%, 5%, and 10%, we reject the null hypothesis for all variables across all South

Asian countries and accept the alternative hypothesis based on relevant test statistics and corresponding probability values.

2.1. CIPS Second Generation Panel Unit Root Test

This required second generation panel unit root test that account for cross sectional dependency.

Table 4: CIPS Result

Variable	Level	I^{st} Diff	Decision
ECFO	-1.54	-5.26	I(1)
EP	-2.61	-4.87	I(0)
FDI	-1.70	-4.52	I(1)
GDP_{pc}	-1.17	-2.10	I(1)
FD	-1.25	-3.00	I(1)
Critical Values			
	1%	5%	10%
	-2.6	-2.34	-2.21

Note: Author's Calculations

Table 4 reports the estimates of cross-sectionally augmented Im, Pesaran, and Shin (CIPS) tests of unit roots. The null hypothesis of this test is rejected when the calculated value falls below the critical value. All the variables in South Asian countries are exhibiting integration of order one, except energy poverty, which exhibits integration of order zero. This shows the presence of mixed orders of integration among variables of our analysis. Some variables are I(1) and others are I(0).

2.2. Panel ARDL

Panel ARDL (Pool Mean Group) approach is useful when dealing with mixed order of integration, where some variables are stationary at the level and others are stationary at the first difference. PMG combines both fixed and random effect models. For long-run relationships and mixed order of integration, PMG might be the preferred choice.

Table 5: Pool Mean Group (PMG) Test Results

Pool Mean Group			
Long Run Relationship			
Variables	**Coeff**	**t-statistic**	**Prob**
EP	-0.00	-2.33	0.02
FDI	-0.01	-1.63	0.10
GDP_{pc}	0.02	2.09	0.03
FD	0.00	5.58	0.00
C	0.47	9.57	0.00
Short Run Relationship			
Variables	**Coeff**	**t-statistic**	**Prob**
COINTEQ	-0.23	-1.72	0.08
Δ (ECFO (-1))	-0.07	-0.56	0.57
Δ (EP)	-0.00	-1.61	0.10
Δ (FDI)	0.02	1.25	0.21
Δ (GDP_{pc})	0.05	4.40	0.00
Δ (FD)	-0.00	-0.49	0.62

Table 5 consists of estimates of both long-run and short-run results. The energy poverty negative coefficient value (-0.00) in the long run relationship suggests a strong and statistically significant negative relationship between energy poverty and ecological footprint. EP increase by one unit, the ECFO would be expected to decrease by approximately 0.00 units. The negative coefficient indicates that access to clean energy and technologies for cooking and the use of renewable energy sources tend to decrease the ecological footprint. Due to a shift towards cleaner and more efficient sources, such as renewable energy, there has been a significant reduction in greenhouse gas emission and environmental impacts compared to the use of traditional fossil fuel. The higher share of renewable energy in energy poverty (EP) index shows a significant transition from fossil fuels to clean energy, which significantly contribute to reduce CO_2 emissions and environmental degradation. A higher proportion of electricity sourced from renewables in EP index indicate a cleaner energy mix and decreased reliance on fossil fuels. This transition significantly reduced ecological footprint. These results are similar to Udemba (2020); Ansari et al., (2023) and dissimilar to Fan et al. (2024).

In South Asian countries, the majority of population with limited access to clean fuels and electricity, leading them to rely on traditional sources for cooking, often less efficient and more environmentally damaging energy sources like biomass or fossil fuel. The lack of electrification is another common issue of South Asian nations. A large segment of the population is living without access to electricity, such a population has to rely on nonclean sources of energy for lighting their homes. The third problem in South Asia is the high use of coal in electricity production. Even the more use of electricity, by people, does cause pollution due to non-clean sources of electricity production. At the government level the share of renewable energy is less in total final energy production, and at household level people cannot afford the cost of renewable energy like solar energy and wind energy. So, the people use traditional sources for cooking, which generate carbon emission and increase ecological footprint.

In South Asian countries the FDI net inflow negative coefficient (-0.01) implies that high level of FDI is associated with lower ecological footprint. This suggests that FDI net flows into a country, there may be a lower environmental impact and resource consumption. Many factors such as advanced technologies reduce energy usage, waste generation, and pollution. FDI brings in capital that invests in different sectors of the economy and leads to increased production and income. FDI can help new markets for local products, increase exports and economic diversification. These results are similar to Tran et al., (2024) and dissimilar to Ozcan (2024).

In the long run, the GDP per capita (PPP) has a positive coefficient value of 0.02. GDP_{pc} increase tends to increase ecological footprint due to more economic activity, investment in infrastructure, industrialization, energy consumption, trade, globalization expansion markets depletion of natural resources, and degradation of the environment. This results in comparable outcomes to Magazzino (2024); Rahman et al., (2018); Majeed (2019), and dissimilar to Uddin et al., (2016); and Rehman et al., (2018).

The positive coefficient value of FD is 0.00. This indicates that high FD leads to an increase in the ecological footprint. FD increases economic activity, high consumption, and industrialization which increase ecological footprint. C is the statically significant the intercept term. This result is similar to Dada et al., (2022); Sehrawat et al., (2015), and Baloch et al., (2019).

In the short run COINTEQ is an 'Error correction Term'. COINTEQ (-0.23) is a negative coefficient indicating an adjustment towards a short run to a long run. The negative coefficient indicates that the error is corrected annually at the adjustment speed of 24% towards the long run to the short run, which contributes to reducing the ecological footprint in the short run. ΔECFO (-1) shows the change in ecological footprint from its lagged value. Energy poverty negatively related to ecological footprint in both periods. The negative coefficient of energy poverty increases leads to decreased ecological footprint. The ΔFDI represents a change in foreign direct investment from one period to the next. The positive (0.02) coefficient value of FDI indicates an increase in ecological footprint. In the short run foreign capital increases investment in infrastructure, changes in consumption patterns, and other economic activities leading to short -term increases in ecological footprint.

In the short run (ΔGDP_{pc}) positive coefficient (0.05) indicates a direct relationship between GDP and ecological footprint. Higher GDP per capita correlated with increased consumption level, increased industrial activity, expansion of the manufacturing sector, consumer behavior, and urbanization. The FD (-0.00) coefficient in the short run indicates a decrease in ecological footprint due to efficient resource allocation and better risk management practices These results are similar to Ahmed et al. (2021).

3. Conclusion

The ecological consequences of energy poverty are intricately linked to climate change. Ecological imbalances are caused by limited access to clean energy. When people use fossil fuels like coal or oil for heating and cooking, it releases gases that warm the planet and harm nature. Addressing energy poverty demands a holistic approach that combines improved access to clean and affordable energy with sustainable resource management practices to bring about substantial transformation. In South Asia, many people face energy poverty, they often turn to fossil fuels for cooking and heating. Renewable energy plays a crucial role in reducing the ecological footprint. By adopting an energy stacking model (ESM) in South Asian countries with abundant renewable resources, the region can ensure energy security, reduce greenhouse gas emissions, and promote sustainable development while reducing its ecological footprint. The Environment based on the Kuznets hypothesis of economic growth and environment, there is an existence of direct relationship between economic development and environmental population which has a negative U shape curve. The usage of non-renewable energy, and harmful agricultural land practices affect the environment quality. Foreign direct investment generates job opportunities and raises the income level by introducing new clean technology that increases the efficiency of energy. This study seeks to investigate energy poverty effects on environmental quality in five South Asian countries (Bangladesh, India, Nepal, Pakistan, and Sri Lanka) employing composite measures of energy poverty such as access to electricity, modern technology, renewable energy consumption, and electricity production from renewable sources) are independent variables, and ecological footprint is a dependent, while GDP_{pc} (PPP), financial development (FD), and FDI a control variable. Furthermore, to tackle diverse geopolitical heterogeneity and potential differences in energy poverty and its ecological effects across countries, this study used panel data spanning 2000 to 2021.

For the analysis, the Pesaran CD test suggests cross-sectional dependence because the null hypothesis was rejected at the level of significance in all South Asian countries. Observing the correlation matrix, it is understood that there is a negative, very low correlation below the coefficient between energy poverty and the ecological footprint. The correlation matrix value of 1 shows the perfect positive relationship between variables, while value -1 shows the perfect negative relationship between variables. CIPS test indicates mixed orders of integration. The Hausman test was used for dynamic panel data analysis to decide between the Pool Mean Group (PMG) and Mean Group (MG). Meanwhile, the Pool Mean Group (PMG) was applied as a result. Access to clean fuel and technology and access to electricity improvement tends to decrease the ecological footprint. The consumption of renewable energy in the energy poverty (EP) index signifies a transition from fossil fuels, which significantly contribute to CO_2 emissions and environmental degradation. GDP_{pc} is positively related to the ecological footprint in both periods. Short-term fluctuations in economic variables such as FDI and FD influence the ecological footprint.

In the context of South Asia, where energy poverty and ecological challenges are prominent, policy is to address both issues by investing in renewable energy infrastructure development. This investment helps reduce reliance on fossil fuels but also contributes to promoting environmental sustainability. Placing a price on carbon, such as carbon taxes or a cap-and-trade system can incentivize industries to reduce greenhouse gas (GHS) emissions. Promoting green investments not only helps environment sustainability but also boosts the economy through FDI. Government and stakeholders promote the use of clean and renewable energy sources to protect the environment. Future research could explore the role of green bonds, Investigate digital technologies, social change in the energy sector and environmental conservation efforts, and urbanization and globalization.

To sum up, it's clear that addressing energy poverty is vital for maintaining environmental quality in five South Asian countries. By prioritizing access to clean and sustainable energy sources, the government makes life better for people, keeps them healthier, and protects the environment now and in the future.

In the context of South Asia, where energy poverty and ecological challenges are prominent, policy to address both issues could focus on the following strategies:

Provide subsidies and financial incentives to make clean cooking technologies more affordable and accessible, particularly in rural and underserved areas.

Regional policymakers should focus on attracting more green foreign direct investment (FDI) by updating their investment promotion policies to encourage investments in environmentally friendly energy sectors.

In conclusion, with comprehensive policies, the government effectively tackles the multifaceted issues of economic growth, FDI, financial development, energy poverty, and ecological footprint leading to more sustainable outcomes for present and future generations.

In addition to its contribution, this study has identified several limitations that future research could address. Future studies could consider incorporating other regions like Asia and ASEAN countries with similar variables for interesting results.

By focusing on these emerging research areas, scholars can contribute to advancing knowledge, policy development, and fostering innovative solutions to the complex interactions between energy poverty and ecological sustainability.

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