Energy Intensity, Transmission Losses, and the Ecological Footprint: A Panel Study of Bangladesh, India, and Pakistan

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Abstract

The developing South Asian countries like Bangladesh, India, and Pakistan need to grow their economies and provide energy to millions of people, but at the same time they also need to protect the environment from pollution and climate change effect. This study uses data of these three countries from 1990 to 2024 collected from the World Bank website to compare the green energy transitions. Statistical methods including correlation analysis, panel unit root tests, Pedroni cointegration, and panel regression are used to find out what factors affect the ecological footprint. The results show that renewable energy consumption significantly decreases the ecological footprint (coefficient = -0.017, $p < 0.001$), while energy intensity (coefficient = 0.269, $p < 0.001$) and GDP per capita (coefficient = 0.204, $p < 0.001$) increase it. Exports and electricity line losses also have positive effects on the footprint, but industry share unexpectedly has a negative effect. Unit root tests performed to check the stationarity of variables, most variables are stationary at first difference (I(1)), except electricity losses which is stationary at level I(0). A long-run relationship between the variables is confirmed by the Pedroni cointegration test. The regression model is very good fit as it explains 91% of the variation in ecological footprint. Based on these findings, it is recommended that India continue investing in renewables and energy efficiency, Pakistan reduce transmission losses and energy sector circular debt, Bangladesh expand off-grid and fluctuating solar projects. The main limitation is the small number of countries in the panel, so future research should include more South Asian nations.

Keywords: *Ecological Footprint, Renewable Energy, Energy Intensity, South Asia, Panel Data, Bangladesh, India, Pakistan*

1. Introduction

1.1 Background and Context

South Asia region is the home to nearly two billion people, and it is experiencing rapid economic growth, urbanization, and industrialization. Bangladesh, India, and Pakistan together account for a significant share of the world's population, yet they remain among the lowest per-capita energy consumers globally. Countries like Bangladesh, India, and Pakistan have large populations and fast-growing economies, which means they need more and more energy every year (Qudrat-Ullah,

2023). However, this growth creates a big problem electricity need to millions of people but also need to protect the environment from pollution and climate change. These three countries have similar problems like poverty, population growth, and vulnerability to floods and heatwaves, but they have very different paths for energy needs.

Climate change is already affecting these countries rising sea levels threaten the coastal areas of Bangladesh and India, and extreme heatwaves and flood have become more frequent in India and Pakistan. These environmental challenges mean that the energy choices made today will have consequences in future.

According to recent data from the World Bank (2024), the renewable energy capacity of India has grown faster over the past decade. Yet the country still relies heavily on coal, which accounts for about 67 percent of its electricity generation. The heavily reliance on coal creates challenge for climate commitments and affordable power. India has become a world leader in solar and wind power, investing billions of dollars into renewable energy projects (Rej et al., 2022).

Pakistan has relied on a mix of hydropower and imported fossil fuels. Pakistan has a lot of hydropower potential from its rivers, but it faces problems like political instability and debt in the energy sector (Ahmed et al., 2016). Recently, Pakistan has seen a remarkable surge in solar power adoption, driven by private sector responses to high electricity prices. According to a report from early 2026 solar now provides electricity equivalent to a fifth of Pakistan's grid power.

Bangladesh has focused on small-scale off-grid solar systems for rural homes due to limited land for big solar farms, but it still depends heavily on natural gas (Sarkar et al., 2024). Unlike India and Pakistan, Bangladesh has been slow to adopt solar, with just 1.6 gigawatts of solar capacity compared to Pakistan's 34 gigawatts.

2. Literature Review

Renewable energy consumption and environmental quality relationship has been widely studied in recent years, with most researchers finding a beneficial outcome. Rej et al. (2022) has done study on India using an augmented ARDL approach and the results indicate that when renewable energy consumption increases by 1 percent, the ecological footprint declines significantly. This outcome suggests that investing in solar, wind, and other renewable sources actually brings environmental benefits.

A more recent study by Faizi et al. (2024) examined SAARC countries including Bangladesh, India, and Pakistan using a Method of Moments Quantile Regression (MMQR) approach. The result of their study confirmed that renewable energy consumption significantly decreases both CO2 emissions and the ecological footprint across different quantiles of environmental degradation.

Another recent paper by a group of researchers from Ghazni University and Sakarya University (2026) investigated the impacts of energy intensity, renewable energy, and globalization on environment in SAARC countries using MMQR techniques. Their empirical results, show that renewable energy usage significantly lessens both CO2 emissions and ecological footprint, highlighting the necessity of increasing clean energy sources in SAARC nations.

A study by Sadekin (2025) found that electricity consumption has a significant but relatively small impact on environmental degradation, their work analyzes remittances, electricity consumption, and ecological footprint in South Asia using panel ARDL and MMQR methods. The study indicated that the heavy dependence on fossil fuels in South Asian nations for electricity generation leads to greenhouse gas emissions and air pollution, that degrades environment. This result shows the importance of transitioning to renewable energy sources for the region.

Energy intensity means the energy required to produce one unit of GDP in the economy, that is also a critical factor which affects environmental quality. The study by Shokoohi et al. (2022) found that CO2 emissions increase in Middle Eastern countries due to higher energy intensity, and Rahman et al. (2022) studied the emerging economies and confirmed similar results.

Higher energy intensity shows that inefficient production processes are followed, severely reliance on fossil fuel for energy, resource exhaustion, and environmental degradation. Oth the other hand, less energy intensity indicates the technological advancement and structural change toward less energy-intensive processes and activities. Reducing energy intensity is a major challenge in many South Asian countries because they use old industrial equipment and inefficient and outdated appliances,

A study by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) (2026) says that in South Asia the main obstacle in investing in clean energy and grid upgrades is that the power sectors regularly face the problem of high transmission and distribution losses, obsolete infrastructure, and low bill collection rates. The amount of energy that is generated is not transmitted but a considerable portion is lost in transmission due to system inefficiencies which causes of higher energy intensity. The ESCAP report suggests that for improving system efficiency and strengthening the financial capability of utility sector, the improvement of the transmission infrastructure through grid modernization and digital solutions is required.

A recent news article published in The Economic Times (March 2026) gives a explains that how the globalization and international trade structure are changing energy need and consumption in the region. The article reports that the industries in Pakistan and India are speedily shifting to solar power, reducing their expensive imported fuel demand. This shift is due to high energy cost from grid rather than environmental concerns, but the environmental benefits through this shift are also significant. The article says that solar energy now contributes around to a fifth of grid power in electricity sector of Pakistan, and this has already reduced the demand of imported LNG and oil and thus saved Pakistan about $12 billion. This indicates that by transferring to renewable energy sources the economic incentives and environmental goals both can be achieved.

Hydropower from the Himalayan rivers is one of the most promising opportunities for South Asia regional cooperation. Neupane et al. (2022) claimed that countries like Nepal and Bhutan could export clean electricity to India, Bangladesh, and Pakistan, helping everyone reduce their reliance on fossil fuels. However, political conflicts and lack of trust have disallowed this potential from being realized.

Recent developments suggest that regional cooperation might finally be happened. In November 2025, Tata Power and Bhutan's Druk Green Power Corp signed commercial agreements to jointly develop the 1,125 MW Dorjilung Hydroelectric Power Project. Which is Bhutan's largest public-

private partnership hydro project. The estimated cost of tis project is ₹1.31 trillion, and it will supply 80% of its generation to India by September 2031. This denotes a significant step toward realizing the regional hydropower potential that researchers have been encouraging for.

A World Bank economic update from April 2026 notes that South Asia's growth is projected to slow to 6.3% in 2026 from 7% in 2025 due to interruptions in global energy markets. This economic burden might actually create opportunity for regional cooperation, as countries try to reduce their vulnerability to global energy price shocks.

Researcher have given more attention to India, as it is the largest economy in the region. Rej et al. (2022) given strong indication that renewable energy reduces India's ecological footprint. More recent news reports say that India remains among the fastest-growing major economies, with the World Bank projecting 6.6% growth for FY27. The country has made substantial progress in solar and wind power, but coal still dominates the electricity mix, accounting for about 67% of total generation according to United Nations Economic and Social Commission for Asia and the Pacific data.

Ahmed et al. (2016), who focused on energy security challenges and policy options in Pakistan. The country has momentous hydropower potential but faces political instability, lack of will and circular debt problems in the energy sector. However, recent reports submit that Pakistani industries are swiftly adopting solar power. The CFO of Fauji Cement Co. reported that solar now contributes about 23% of the company's electricity at a cost of just 5 to 6 rupees per kilowatt hour.

Sarkar et al. (2024), who inspected Bangladesh off-grid solar electrification program in their study. The country due limited land for large solar farms has focused on small-scale solar systems for homes in rural areas. But the country still depends heavily on natural gas for electricity generation. According to the comparison towards transformation to renewable energy Bangladesh has been far slower than India and Pakistan.

Research Gap

Majority of the research either considers at one country or combines all South Asian countries, which skips some important differences between these countries. This paper by doing a direct comparison of Bangladesh, India, and Pakistan using the same methods tries to cover that gap and explains why they have different energy pathways. The data for this study will be collected from the World Bank and statistical tests will be conducted to provide specific information to each country how they can make their energy transition faster and easier.

3. Research Questions

1: How different green energy paths are adopted by Bangladesh, India, and Pakistan in relations of renewable energy share, energy intensity, and fossil fuel use?

2: What economic factors and policy drivers explain these different energy paths in these countries?

3: How GDP growth, renewable energy, energy intensity, and exports affect the ecological footprint in these three countries?

4: What policies these countries should adopt for better and faster transition to green energy?

4. Research Objectives

1. To check and compare energy and environmental indicators the tendencies for Bangladesh, India, and Pakistan during the period from 1990 to 2022.
2. To examine the key policy decisions of these countries that formed the energy mix of each country.
3. To statistically estimate the effect on the ecological footprint by renewable energy, GDP, energy intensity, exports, industry share, and electricity losses in these countries.
4. To give specific policy recommendations based on the results for each country.

5. Methodology

This study uses a quantitative approach with secondary data gathered from World Bank World Development Indicators (WDI) for the period 1990-2024 for each of the 3 countries.

5.1 Variables

- **LNEF:** Log of Ecological Footprint (dependent variable)
- **LNCO2:** Log of CO2 emissions
- **RE:** Renewable energy consumption (% of total final energy)
- **LNEI:** Log of Energy Intensity
- **LNGDP:** Log of GDP per capita
- **EXP01:** Exports of goods and services (% of GDP)
- **INDUS:** Industry value added (% of GDP)
- **ELEC_LOSSES:** Electricity transmission and distribution losses (% of output)

6. Results

6.1 Descriptive Statistics

The below Table 1 shows the descriptive statistics for all variables. The mean ecological footprint (LNEF) is -0.365, which is a negative number because it is logged, but the standard deviation (0.296) shows there is variation across countries and time. Renewable energy (RE) has a mean of 45.5% with a range from 24.3% to 73.1%, showing that these countries have very different levels of renewable energy use.

Table 1: Descriptive Statistics

Variable	Mean	Std. Dev.	Skewness	Jarque-Bera (Prob)
LNEF	-0.365	0.296	-0.961	0.000
LNCO2	-0.401	0.679	-0.716	0.010

RE	45.502	10.778	0.239	0.603
LNEI	6.954	0.410	-0.203	0.123
LNGDP	14.210	4.647	0.561	0.026
EXP01	24.642	4.317	0.366	0.127
INDUS	17.917	6.214	0.197	0.660

6.2 Correlation Analysis

The correlation matrix results illustrated in Table 2 show that LNEF and LNCO2 are very highly correlated (0.97), this because the both measure environmental damage. Renewable energy (RE) is negatively correlated with LNEF (-0.70) and LNCO2 (-0.68), that indicate the that renewable energy reduces ecological footprints and CO2 emissions.

Table 2: Correlation Matrix

	LNEF	LNCO2	RE	LNGDP
LNEF	1.00			
LNCO2	0.97	1.00		
RE	-0.70	-0.68	1.00	
LNGDP	0.79	0.71	-0.79	1.00

6.3 Cross-Section Dependence Test

The below table 3 shows the Breusch-Pagan LM test and Pesaran CD test results show the cross-section dependence. This means, what happens in one country affects the other, perhaps due to trade connection, shared rivers, and regional economic links between these countries.

Table 3: Cross-Section Dependence Test

Test	Statistic	Prob.
Breusch-Pagan LM	16.62	0.0008
Pesaran CD	3.36	0.0008

6.4 Unit Root Tests

The panel unit root test results are summarized in Table 4. The Im, Pesaran and Shin (IPS) test is used to check the stationarity of the data. All variables are non-stationary at level except ELEC_LOSSES having p-values greater than 0.05. However, at first difference, all variables become stationary ($p < 0.05$). This mixed order of integration (I(0) and I(1)) is important and gives the direction for choosing the right estimation method.

Table 4: Summary of Unit Root Tests (IPS)

Variable	Level (p-value)	1st Diff (p-value)	Conclusion

LNEF	0.4079	0.0000	I(1)
LNCO2	0.6154	0.0000	I(1)
LNEI	0.8452	0.0000	I(1)
LNGDP	1.0000	0.0002	I(1)
RE	0.3897	0.0000	I(1)
INDUS	0.8640	0.0000	I(1)
EXP01	0.3191	0.0000	I(1)
ELEC_LOSSES	0.0278	0.0000	I(0)

6.5 Cointegration Test

The Pedroni test conducted for cointegration as most variables are I(1). Table 5 shows the results for the LNEF (log ecological footprint) model. the Panel PP-Statistic (-3.03, p=0.0012), Panel ADF-Statistic (-2.61, p=0.0045), and Group PP-Statistic (-7.04, p=0.0000) all reject the null hypothesis of no cointegration. According to these results there is a long-run relationship between ecological footprint and the independent variables (RE, LNEI, LNGDP, EXP01, INDUS, ELEC_LOSSES). In second model For the LNCO2, the results were not significant ($p > 0.05$ for most tests), indicating CO2 might not have a stable long-run relationship with these independent variables.

Table 5: Pedroni Cointegration Test (LNEF Model)

Test	Statistic	Prob.
Panel PP-Statistic	-3.036	0.0012
Panel ADF-Statistic	-2.612	0.0045
Group PP-Statistic	-7.042	0.0000

6.6 Regression Results

Table 6 shows the results of panel regression with LNEF as the dependent variable.. The model has an R-squared of 0.911, meaning it explains 91% of the variation in ecological footprint, which is very good.

Table 6: Regression Results (Dependent Variable: LNEF)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1.256	0.554	-2.268	0.0255
RE	-0.017	0.002	-6.718	0.0000
LNEI	0.269	0.028	9.308	0.0000
LNGDP	0.204	0.055	3.713	0.0003
EXP01	0.008	0.002	3.749	0.0003
INDUS	-0.017	0.003	-4.396	0.0000
ELEC_LOSSES	0.010	0.002	4.866	0.0000

R-squared = 0.911, Adjusted R-squared = 0.905, F-statistic = 167.43 (p=0.000)

The results of the study show that RE (Renewable Energy) is statistically significant as the coefficient is -0.017 ($p<0.001$). This means a 1 percentage point increase in renewable energy share reduces the ecological footprint by 0.017%. This is and supports the literature. A 1% increase in energy intensity increases the ecological footprint by 0.27%. This is badly affecting the environment as LNEI (Energy Intensity) Coefficient is +0.269 ($p<0.001$). LNGDP (GDP per capita**)** coefficient is +0.204 ($p<0.001$). that indicates when GDP per capita increases by1% it increases EF by 0.20%. This is an indication that economic growth in these countries affects the environment. EXP01 (Exports) Coefficient is +0.008 ($p<0.001$). More exports lead to a higher footprint, but the effect is small. INDUS (Industry share) Coefficient is -0.017 ($p<0.001$). Surprisingly, a higher share of industry in GDP reduces the ecological footprint. This might be because industry in these countries is becoming cleaner or because agriculture is actually more damaging. ELEC_LOSSES Coefficient is +0.010 ($p<0.001$). Higher electricity losses increase the footprint. Improving grid efficiency would also be helpful for the environment.

7. Discussion

The negative and significant coefficient of Renewable energy (RE) confirms the Rej et al. (2022) and Faizi et al. (2024) findings that growth of renewable energy reduces ecological footprint and CO2 emission thus reduces the damage to the environment. India is gaining environmental benefits due to increased investment in renewable energy especially on solar and wind. However, the low improvement in ecological footprints of Bangladesh and Pakistan describes their less investment and growth in renewable energy.

The high coefficient (0.269) of energy intensity that is largest among all variables, indicates that these countries utilize a huge amount of energy to produce each unit of GDP. This is common in developing countries due to their old factories, inefficient equipment and technology, and poor planning for urbanization. Advanced technology and efficiency standards should be the top priority of these countries to reduce the energy intensity.

The positive relationship between GDP and EF suggests that the turning point of Environmental Kuznets Curve yet to be reached by these countries. Unlike the study by (Rej et al., 2022) that found an inverted U-shape for India, our panel results show that growth still comes at the cost of environmental degradation. This might be because these three countries are at different stages of development, and combining them together skips the patterns of individual country.

The negative coefficient for industry is surprising, this might be due to the improved modern technology and foreign investment that brings modernization in industry in South Asia or might be due to the agricultural sector, which is still large sector of production in these countries.

Electricity losses in Bangladesh and Pakistan are very high and the positive coefficient for ELEC_LOSSES shows that reducing transmission and distribution losses would not only save money but also reduce the environmental damage through the reduction of ecological footprint in these countries.

These countries are neighbor and linked with each other as cross-section dependence test result shows, this supports the argument by Neupane et al. (2022) for regional cooperation. If India builds more hydropower projects, it can export electricity to Bangladesh and Pakistan, reducing everyone's reliance on fossil fuels electricity generation.

8. Conclusion

This study analyzed and compared the green energy transitions of Bangladesh, India, and Pakistan using panel data from 1990 to 2024. The results of this study suggest that renewable energy reduces the ecological footprint, while the other independent variables like energy intensity, GDP growth, exports, and electricity losses increase the ecological footprint. As per the results industry share unexpectedly reduces the footprint, this because due to efficiency by modern technology increased foreign investment in these countries. Most variables are I(1) the results of the unit root tests showed, and the Pedroni cointegration test confirmed a long-run relationship. The regression model very strong as it explained 91% of the variation in EF.

The small number of countries (only 3) is the limitation of the study, which limits the power of panel tests. Also, the limited degrees of freedom, do not allow to run separate time-series models for each country. The Durbin-Watson statistic of 0.42, suggests positive serial correlation which is another limitation. This means that the standard errors might be underestimated, even though we used cluster-robust standard errors in the fixed effects model.

9. Policy Recommendations

Based on our findings, we recommend the following:

India should continue investing in renewable energy especially in solar and wind power, as renewable energy clearly reduces the footprint. Focus on reducing energy intensity by promoting energy-efficient appliances and better technology, green building codes, and electric vehicles. Use export policy to encourage green technologies and discourage dirty industries.

Pakistan should address circular debt in the energy sector to make renewable energy projects financially viable and feasible. Reduce transmission and distribution losses, which have a coefficient of +0.010. Upgrading the grid and transmission infrastructure would have immediate environmental benefits. Develop hydropower sector in a sustainable way, but also diversify into solar to reduce dependence on any single source and to reduce fossil fuel dependency.

Bangladesh should expand off-grid solar programs, which have been successful in rural areas and invest in large projects. Reduce dependence on natural gas and diversify into renewable sources of wind and solar. Improve energy intensity in the garment industry, which is the main export sector of the country.

For better regional cooperation the countries should create a South Asian power grid to allow trading of hydropower from Nepal and Bhutan to India, Bangladesh, and Pakistan to reduce the heavily dependency of fossil fuel of their energy sector. Establish a regional and mutual fund for renewable energy projects to reduce costs through economies of scale for the benefit of the region. Harmonize environmental standards and renewable energy certificates so that green energy can be traded across borders to other countries in the region.

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