International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(4), 189-203.

From Energy Diversity to Environmental Resilience: The Role of Government Efficiency in Shaping Ecological Footprint in Bangladesh

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Received: 30 December 2024 **Accepted:** 01 May 2025 **DOI:** https://doi.org/10.32479/ijeep.18955

ABSTRACT

Given the significance of governmental stability, energy usage, and economic development in improving ecosystem health, it is essential to analyze the interrelationship among rise in GDP, energy dynamics, government effectiveness, and ecological footprint (EF). This study utilized Bangladesh's annual data from 1995 to 2021. The investigation applied the ADF, PP, and DF-GLS unit root tests to assure the existence of unit root issues in the dataset. The ARDL bound testing methodology was utilized to explore the effect of independent factors on the EF in both short and long-term. The outcomes reveal that GDP expansion substantially elevates EF in both the short term and the long term. Conversely, both government effectiveness and the consumption of sustainable power show a significant negative correlation with EF over both time periods, suggesting that these factors positively influence the health of the ecosystem. Furthermore, the use of non-renewable energy and urbanization show a positive connection with EF in both time periods, highlighting their significant influence on ecological condition in Bangladesh. The ARDL model's validity was affirmed via FMOLS, DOLS, and CCR estimate methods. The analysis advocates for the implementation of legal rules to facilitate a green environment, enhance the use of clear electricity, promote stable governance, and higher funds in sustainable energy to minimize pollutants and attain sustainability in Bangladesh.

Keywords: Energy Use, Government Effectiveness, Ecological Footprint, ARDL, Bangladesh
JEL Classifications: Q53, O44, R11, G28

1. INTRODUCTION

In emerging nations, ecological stress increases more swiftly than income through the beginning of monetary expansion and diminishes relative to growth in income at stronger socioeconomic status. Ecosystems are deteriorating, an indisputable reality that has resulted in numerous cautionary indicators. Some have referred to this condition as a disaster for world diversity and ecological viability (Jiang et al., 2024). The UN has lately tackled this problem by establishing a worldwide context at the UN ecological summits (Pata et al., 2025). Bangladesh is a swiftly developing South Asian nation, characterized by growing populations and a declining environment (Rahman et al., 2018; Ratna et al., 2024). Bangladesh is the smallest nation, with 147,570 square kilometers, although it has a substantial population of 161.36 million (World Bank, 2021). Although Bangladesh accounts for <1% of the global CO_2 output, it remains greatest climate-susceptible regions. The nation has demonstrated an unwavering dedication to fulfilling the SDGs established in the Paris Agreement (Mehta et al., 2018). Bangladesh aims to produce 40% of its power from clean resources by 2041, with its draft regional solar energy strategies proposing approximately 41 gigawatts of solar energy within that period (Islam, 2022). The Global Climate Risk Index 2021 ranked Bangladesh 7th across nations highly impacted by global warming, presenting an additional risk to the country's financial viability (Raihan et al., 2022). Climate change-related challenges caused Bangladesh to incur losses of around USD 3.72 billion from 2000 to 2019, and this figure is likely to increase if the government fails to adopt effective sustainable solutions (Islam, 2021). This current study has selected Ecological Footprint (EF) as a proxy for ecosystem conditions as an endogenous factor to check how government effectiveness, GDP growth, usage of green and non-green energy, and urbanization affect the environmental resilience of Bangladesh. Ecological footprint (EF) studies have come a long way in the past few years, both locally and globally (Tingli et al., 2025). These studies have mostly focused on improving models (Liu et al., 2022), looking at trends over time and space (Xun and Hu, 2019), and finding out what forces are at play (Yasin et al., 2025). The EF consistently expands in tandem with rising GDP, population growth, energy consumption, and reliance on basic sources of power, thereby diminishing the earth's biocapacity (Javeed et al., 2023). To optimize present well-being without compromising the ability to fulfill future generations' requirements, ethical approaches must be implemented through the amalgamation of monetary and ecological factors (Musa et al., 2024). Therefore, the current global priority is to tackle ecological degradation by establishing effective governance that prioritizes the preservation of energy resources, human life on Earth, and a sustainable environment.

Bangladesh has experienced rapid socioeconomic growth in the past decade, despite significant environmental degradation (Gupta et al., 2022; Huda, 2024). The nation's environmental quality fundamentally influences economic growth in various ways (Bennaceur et al., 2025; Onakpojeruo et al., 2025). Initially, a higher GDP may positively contribute to biodiversity loss by upsurging the use and exploitation of energy and natural resources. Furthermore, elevated GDP may amplify innovation by fostering technological advancements, environmentally sustainable products, and economic efficiency, thereby reducing the generation and usage costs of clean electricity (Can and Gozgor, 2017). Several studies have shown positive (Suki et al., 2020; Li et al., 2022) and negative (Mohsin et al., 2022; Haq et al., 2024; Ali et al., 2024) influence of GDP on environmental quality. Conversely, the significance of sustainable power is becoming evident as the globe grapples with temperature rise and the necessity for equitable growth. According to a projection, the global economy will double by 2050 due to significant GDP growth and population expansion, which will lead to a roughly 50% increase in energy demand (Brugger et al., 2021). The sustainability issue, propelled by greenhouse gas emissions (GHG) and loss of biodiversity, necessitates a shift to renewable energy for long-term prosperity (Yıldırım et al., 2025). For example, choices about fossil fuel usage result in the discharge of contaminants into the atmosphere, thereby degrading the ecosystem (Hanif et al., 2019). In opposite side, Murshed et al. (2021) proposes the adoption of renewable energies as a substitute to enhance the environment. Consequently, substituting conventional fossil fuels with more contemporary and greener options is considered a promising approach for rebuilding global ecological balance (Nathaniel et al., 2021). The present state of green electricity in Bangladesh provides a thorough analysis of the nation's capacity to execute sustainable energy solutions (Bahaj et al., 2025). Prior to recent advancements in hydroelectric, solar, and wind energy, the nation relied heavily on traditional fossil fuels, leading to significant environmental impacts (Chandratreya, 2025). Bangladesh targets 16% renewable energy generation by 2030, but the IEA's Net Zero Emissions forecast establishes a worldwide objective of 60% renewable electricity by the same year (Ember, 2024). Government programs that garner significant attention influence the trajectory of renewable energy in Bangladesh. The emphasis is on societal benefits such as enhanced employment, energy security, and rural electrification; however, there are also downsides such as inadequate finance and infrastructure (Puri et al., 2025).

Gulagi et al. (2020) suggest that Bangladesh's transition to renewable energy may commence with the depletion of fossil fuel sources, anticipated between 2030 and 2050. The full transition is expected to occur in the later part of the century, with renewable energy technology being crucial in substantially decreasing carbon emissions and tackling enduring environmental and economic issues (Bogdanov et al., 2021; Shufian et al., 2025). As a result, the authority is prioritizing the development of renewable energy facilities above conventional fossil fuel plants to satisfy the substantial power adoption of the country, influenced by Bangladesh's advantageous geographical position (Hossain et al., 2015). Protective measures for environmental sustainability have consistently increased (Donkor et al., 2025) in recent years, particularly in emerging regions such as Bangladesh, which is considered a negligible source to pollutants globally but remains vulnerable to the effects of ozone layer depletion and global warming. As urban environmental challenges become increasingly apparent, governmental focus on ecological problems is intensifying (Wang et al., 2024). Alsayegh et al. (2023) underscore the beneficial correlation within national governance, sustainability reporting, and the fulfilment of SDGs. Furthermore, political stability, governmental efficacy, and accountability—in conjunction with global economic integration—are essential for cultivating a climate conducive to sustainability. This highlights the significance of global governance in establishing a stable and accountable framework that fosters environmental and economic sustainability (Guan and Qamruzzaman, 2022; Adanma and Ogunbiyi, 2024). Furthermore, Bangladesh's urban population increased from 7.9% in 1971 to 38.2% in 2020, with a yearly pace of 3.29% (World Bank, 2021). Consequently, rural to urban relocation is expected to increase in the next years, exacerbating ecological damage (Ahmed et al., 2020). Furthermore, the processes of urban growth and modernization in Bangladesh ended up in a significant rise in the consumption of non-renewable energy. As a result, these conditions lead to detrimental consequences, notably environmental degradation as well as the rise of healthcare hazards (Musa et al., 2022).

This work substantially enhances the present corpus of knowledge in different critical dimensions. The paper has analyzed the substantial influence of many selected elements on Bangladesh's environmental conditions. Results from this research demonstrate a positive correlation between Bangladesh's efficient governance, green power adoption, and EF. This study incorporated the ARDL bound test to explore the short- and long-term connection within the endogenous and exogenous variables. This empirical analysis relies on time series econometrics spanning from 1995 to 2021. Additionally, to ensure the validity of the conclusions, we employed FMOLS, DOLS, and CCR estimations as robustness inspections. This inquiry is crucial for Bangladesh, since it provides a comprehensive analysis of how energy dynamics and governmental effectiveness impact environmental resilience, a critical element in the nation's financial and societal advancement. Moreover, it demonstrates the necessity of strategic investments in alternative energy, urban planning, and efficient administrative facilities to promote environmentally sustainable and inclusive development, illustrating the beneficial effects of governmental stability and clean power on the natural world. Furthermore, this paper reveals the imperative for policy interventions to improve equitable prosperity opportunities, optimize urban design, shift from non-renewable to renewable energy, and address the comprehensive needs of individuals in order to foster environmentally sustainable practices. Lastly, it provides policies into the ideal stages of equitable financial ability, governmental efficacy, necessary human resources, and sustainable urban design, aimed at enhancing ecosystem health through green electricity utilization. From a legislative standpoint, these results offer significant direction for establishing thresholds to improve environmental sustainability in developing nations. Consequently, it reinforces the nation's primary development goals.

The subsequent sections of this research are presented as below: Section 2 examines the relevant existing literature. Chapter 3 delineates the model design, temporal scope, and sources of information. Part 4 delineates the findings and provides a concise commentary. Section 5 ends the study, addressing particular policy consequences, limits, and avenues for further study.

2. LITERATURE REVIEW

Many scholars are currently studying ecological economics and adding to the corpus of information on particular topics. Numerous studies examine the factors influencing damage to the environment. The following part analyzes research addressing the link within ecological footprints as a proxy of ecological damage: GDP, GE, RE, NRE, and URBA.

2.1. GDP and EF Nexus

There is a lot of evidence that long-term GDP growth adversely impacts EF, leading to ecosystem destruction (Abbasi et al. 2021). For example, Siakamba et al. (2025) utilize information from 1990 to 2021 to observe the implication of GDP and RE on the EF in Zimbabwe. They used the ARDL bound test and revealed that GDP adversely affects the EF. Tiwari et al. (2025) explore the correlation of ICT use, GDP expansion, CO_2 emissions, and EF from 1990 to 2021 in the USA. By adopting the ARDL structure they demonstrated an encouraging relation within GDP growth and CO_2 emissions and EF. Warsame et al. (2025) evaluate the legitimacy of the EKC curve by integrating the implications of clean electricity, GDP, and globalization on EF in IGAD member states. The findings of the PMG model observe that increased economic expansion correlates with a decline in ecological health. Moreover, Acar et al. (2023) demonstrates the effect of GDP development on the EF in Azerbaijan from 1996 to 2017. By incorporating the ARDL bound test approach they confirmed that rise in GDP influences the country's impact on the planet. At the same way, Uzar and Eyuboglu (2023) in USA, Riaz et al. (2024) across BRICS region, Ahmed et al. (2019) within Malaysia also observed same outcome. Conversely, the expansion of economic activity often leads to the implementation of gauges that mitigate adverse environmental effects, including advancements in innovation and effectiveness, more stringent environmental laws, or transitions to less harmful sectors (Bakht, 2020). Mohammed et al. (2024) evaluate the influence of GDP expansion on the environment from 1990 to 2019. They suggest that GDP growth within the EU has progressed to a point where economic expansion benefits the natural world. Moreover, Zubair et al. (2020) investigate whether GDP and increment of FDI diminish CO_2 releases in Nigeria from 1980 to 2018. Utilizing ARDL bounds testing for cointegration and Vector Autoregressive (VAR) methodologies, they determined that GDP decreased CO_2 emissions in Nigeria.

2.2. Government Effectiveness and EF Nexus

Numerous studies indicate that governance significantly influences the state of the environment (Li and Reuveny, 2006). A robust government enhances ecological integrity, as elected officials are capable of delivering public services and fostering ecosystems for citizens to participate in (Farzanegan and Markwardt, 2012; Halkos and Paizanos, 2013). Hassan et al. (2024) employ the FMOLS estimation to review the influence of governance quality and ecosystem investments on CO_2 emissions from 1996 to 2020 in BRIC economies. Their findings suggest that governmental expenditures on conservation efforts result in a fall in CO_2 emissions. The efficacy of this spending relies on the degree of governance. Bildirici et al. (2022) assert that effective administration is essential for advancing ecological legislation and reducing CO_2 outputs. The efficiency of government positively contributes to the reduction of pollutants and the facilitation of academic and technological initiatives aimed at atmospheric enhancement (Gani, 2012; Yasmeen et al., 2018). Conversely, Waris and Din (2024) examined the government's influence on CO_2 emissions from 1993 to 2021. Utilizing several novel methodologies, they determined that an effective government governance system significantly positively influences CO_2 emissions resulting from industrialization. Abid et al. (2021) identified poor regulation, unstable politics, and insufficient prevention of corruption as primary factors contributing to pollutants in Sub-Saharan African nations. They examined the major influence of government effectiveness on CO_2 emission levels. Moreover, Yang et al. (2022) explore the relationships among EF, sustainable power usage, and government efficacy across 27 African nations from 1990 to 2018. They the ARDL framework to observe the symmetric consequence and the nonlinear ARDL method to explore the asymmetric implications of the factors on EF. The findings reveal that a 1% increment in GE is assumed to elevate EF by 0.04% in Africa but exerts no influence on the natural world in nations with ecological deficits.

2.3. Renewable Energy and EF Nexus

Renewable energy markedly decreases CO_2 emissions; yet its role in fostering long term financial development is a somewhat novel area of study (Lee and Lee, 2022). The use of RE sources is crucial for alleviating the detrimental consequences of many elements on the ecosystem and advancing ecologically friendly strategies (Uddin et al., 2023). Sun et al. (2025) observed the contributions of RE, and GDP to the ecological viability of G-20 nations. This study adopted the MMQR technique and revealed that the utilization of green power is detrimental to ecological health. Rao et al. (2024) analyze 38 nations from 1994 to 2020 to explore the determinants of the EF across OECD and BRICS economies. They found that green power reduces the levels of pollutants in the designated area. Mohamed et al. (2024) applied the ARDL framework to investigate the implication of electricity intensity and green power in electricity generation on Malaysia's CO_2 emissions and EF. The study indicates that although electricity uses correlates with heightened pollutants, the utilization of clean energy resources for power production might facilitate lower emissions. Kirikkaleli et al. (2022) examine the impacts of RE utilization on CO_2 releases in Chile. By using the ARDL bounds in conjunction with Kripfganz and Schneider's (2018) estimates, they illustrate that the adoption of sustainable energy mitigates consumer-based CO_2 emissions. The same result is observed by multiple researchers like Sharma et al. (2021), Murshed et al. (2022), Ahmad et al. (2024), Caglar et al. (2025), Dogan et al. (2022), Ahmed et al. (2021), and Samour et al. (2024). On the flip side, Idroes et al. (2023) introduced a fresh way by illustrating the effect of biomass and geothermal power on CO_2 releases, suggesting that not all RE resources possess identical ecological consequences.

2.4. Non-Renewable Energy and EF Nexus

Several publications have analyzed the potential long-term connection within RE and NRE sources and economic expansion, as well as its implications for ecosystem stability. For example, Adekoya et al. (2022) implemented the AMG to evaluate the effects of NRE and RE consumption on EF. They observe that non-green power adoption in both categories of countries substantially contributes to ecosystem damage. Sharif et al. (2020) re-examine the consequence of clean and NRE usage on Turkey's EF. They employed the Quantile ARDL methodology and indicated that non-renewable energy favorably affects the EF in both time periods across all quantiles. Destek and Sinha (2020) look into whether the EKC hypothesis about EF is true. They do this by looking at how trade openness, RE and NRE use affected 24 OECD regions. By adopting second-generation panel data techniques, they determined that an expansion in NRE consumption exacerbates ecological damage. Additionally, Kazemzadeh et al. (2022) explored the implication of NRE on the EF by using the panel quantile regression from 1990 to 2014. It was determined that GDP and NRE usage are factors contributing to ecological degradation. Similarly, Kartal et al. (2023) within Turkey, Hanif et al. (2019) in Asia, Voumik et al. (2023) in Kenya, Kongkuah (2024) across Belt and Road countries observed that use of non-renewable energy degrades the environment quality. Conversely, Idroes et al. (2024) explored the effects of NRE (coal, gas, and oil), clean energy, and GDP development on CO_2 emissions and the EF in Indonesia from 1965 to 2022. By adopting FMOLS and DOLS, they demonstrate that a rise in coal and gas directly leads to elevated CO_2 emissions, yet it does not influence EF. In contrast, each rise in oil influences the escalation of EF but not CO_2 emissions.

2.5. Urbanization and EF Nexus

Contemporary human civilization and access to commodities are intrinsically linked to urban growth (Nuţă et al., 2024). Prior research substantiates the notion that manufacturing and urbanization are the primary sources of pollutants (Sufyanullah et al., 2022). Danish et al. (2020) examine the correlation among RE, URBA, and EF in BRICS nations from 1992 to 2016. They incorporated the FMOLS and DOLS long-run estimators, revealing that URBA reduces EF, indicating a beneficial impact on environmental quality. Sahoo and Sethi (2022) analyze the influences of URBA, GDP, and population density on EF in NICs from 1990 to 2017. They employ the MG and PMG approaches to analyze the long-run and short-run connections within the factors, revealing that urbanization positively influences EF over time. Similarly, Hassan et al. (2019) within Pakistan, Ahmed et al. (2020) within China, Gupta et al. (2022) within Bangladesh and Alam et al. (2024) in India found same favorable conclusions. Urbanization impacts the ecosystem through several mechanisms; as urbanization and industrialization progress, the proliferation of factories and structures in the area surpasses the waste recycling capacity of the biodiversity (Feng et al., 2019). Raihan et al. (2022) observe the effect of GDP expansion, RE adoption, and URBA on CO_2 emissions in Bangladesh from 1990 to 2019. They explored that urbanization elevates CO_2 releases. Hassan et al. (2025) examine the impacts of RE usage and URBA in South Asia from 1990 to 2018. The researchers employed multiple methodologies, concluding that URBA exacerbates environmental contamination. At the same way, Ulucak et al. (2020) within emerging countries, Mahmood et al. (2020) in Saudi Arabia, Arif et al. (2023) in Pakistan, Sabir and Gorus (2019) across South Asia, Sarker (2024) within Bangladesh also demonstrated same observation.

2.6. Literature Gap

The evidence-based study above provides a comprehensive array of research findings about the elements affecting EF. The aforementioned findings show that few investigations have utilized CO_2 emissions, EF, and LCF as proxies for ecosystem health. This analysis reveals divergent results regarding the influence of multiple elements on ecological footprints, highlighting the ongoing need for further examination to illustrate the connection within these components and the independent factors. It differentiates considerably from other studies by concurrently presenting EF as an endogenous factor while integrating novel external factors, such as government effectiveness and both RE and NRE usage in Bangladesh. Consequently, the investigation aims to evaluate and juxtapose the impact of numerous drivers on the damage to the environment. Therefore, the asymmetric consequences for EF lead to improved strategies aimed at achieving sustainable cities and communities and tackling global warming (SDGs 11 and 13, respectively).

3. METHODOLOGY AND DATA

3.1. Data and Variables

This analysis utilized information from the GFN, UNCTAD, and WDI spanning 1995-2021 to analyze the consequences of GDP, government effectiveness, RE and NRE, and urbanization on EF in Bangladesh. We selected this nation for evaluation based on its geographical characteristics, ecological circumstances, and the availability and integration of its statistical data for our current study needs. Table 1 represents detailed statistics about the selected variables, like their details, units of measurement, and sources. This research employs the EF as the endogenous variable. The trustworthy GFN provided the EF figures, measured in Gha per person. Conversely, the most esteemed WDI included statistics on GDP per capita in US dollars, as well as information on renewable and nonrenewable energy and urbanization. Furthermore, we sourced data on government effectiveness from a reputable and recognized entity, like UNCTAD. Therefore, improving the flexibility and validity of the methodology of this research guarantees that the complete paper delivers an obvious and cohesive assessment.

3.2. Theoretical Framework

During the 1960s, biologist Commoner proposed that ecological problems stemmed from insufficient innovation, not from population growth or increasing wealth (Krishnendu and Patra, 2025). Ehrlich and Holdren (1971) responded by emphasizing the relevance of each element, including population (P), affluence (A), technology (T), and other macroeconomic considerations, thereby creating the IPAT equation.

$$I = \int PAT \tag{1}$$

Here, "P" represents population size, "A" signifies wealth, "T" means technological advancement, and "I" refers to environmental effect. This framework is intensely concentrated to demonstrate the implication of business operations on energy usage and environmental outcomes (Borsha et al., 2024; Usman and Hammar, 2021). The greatest drawback of this model is its insufficient focus on the variables that induce non-proportional and non-monotonic changes (York et al., 2003).

Consequently, Dietz and Rosa (1994; 1997) developed the STIRPAT structure to reduce the drawbacks of the IPAT framework. When measuring the elasticity of influence for each variable, the STIRPAT model is more accurate and works better with a wider range of data types, such as cross-sectional, time-series, and panel data (Akther et al., 2025; Ge et al., 2018). They additionally contemplate the subsequent version:

$$I_{it} = CP_{it}^{\varphi 1} A_{it}^{\varphi 2} T_{it}^{\varphi 3} \varepsilon_{it} \tag{2}$$

The logarithmic version of this formation is given below:

$$lnI_{it} = C + \varphi_1 lnP_{it} + \varphi_2 lnA_{it} + \varphi_3 lnT_{it} + \varepsilon_{it} \tag{3}$$

The variables employed in our study included ecological footprints as a measure of impact (I), urbanization as a demographic indicator (P), wealth (assessed by GDP and GE), and technological advancement (RE and NRE). This is an innovative application of the conceptual paradigm grounded in the present pertinent literature:

$$EF_{it} = f\,(GDP_{it}, GE_{it}, RE_{it}, NRE_{it}, URBA_{it}) \tag{4}$$

In this context, GDP signifies economic growth, GE represents government effectiveness, RE denotes renewable energy, NRE refers to non-renewable energy, and URBA pertains to urbanization. This investigation integrates these variables to conduct an extensive examination of the alterations in Bangladesh's EF and its driving forces, thereby providing a scientific foundation for sustainable growth in the area. The econometric concept posits that model variables should be logarithmic to mitigate any heterogeneity effects (Lin et al., 2017; Kazemzadeh et al., 2023). Consequently, Equation (4) is logarithmically transformed, resulting in Equation (5), as demonstrated.

$$LEFP_{it} = \lambda_0 + \lambda_1 LGDP_{it} + \lambda_2 LGE_{it} + \lambda_3 LRE_{it} + \lambda_4 LNRE_{it} + \lambda_5 LURBA_{it} \tag{5}$$

Here, λ_0 represents the intercept term, whereas λ_1, λ_2, λ_3, λ_4 and λ_5 denote the coefficients of the chosen explanatory factors, respectively. The letter ε indicates the model's error term, whereas L symbolizes the natural logarithm, appearing prior to each element.

4. EMPIRICAL STRATEGY

The research aimed to explore the relationships between EFP, GDP, government stability, URBA, and RE and NRE in Bangladesh. We employ an ARDL limit test to analyze the time series data. Furthermore, we conducted robustness assessments using the

Table 1: Data and variables

Variables	Description	Long form	Unit of measurement	Source
LEF	Ecological footprint	LEF	Gha per person	GFN
LGDP	Economic growth	LGDP	Gross domestic product (current US$)	WDI
LGE	Government effectiveness	LGE	Government effectiveness, estimates	UNCTAD
LRE	Renewable energy	LRE	Renewable energy use (% of total energy consumption)	WDI
LNRE	Non-renewable energy	LNRE	Fossil fuel energy use (% of total energy use)	WDI
LURBA	Urbanization	LURBA	Urban population, total	WDI

FMOLS, DOLS, and CCR estimations. The initial deployment will concentrate on the unit root test to assess the stationarity of the factors. Furthermore, we conducted multiple diagnostic evaluations to explore the durability and integrity of the data collection. Ultimately, we will select the econometric approach that yields the utmost efficient and reliable outcomes through an estimation procedure.

4.1. Unit Root Test

The study looks at the relationships between elements to see if the statistics is uniform at I(0) or I(1). It is important to note that first-order integration and fluctuations are not necessary. Furthermore, the avoidance of I(2) sequences is problematic, as conclusions may be erroneous due to nonstationary variables and issues related to small sample sizes (Raihan et al., 2025). A lot of previous research has supported using traditional unit root assessments, like the ADF (Dickey and Fuller, 1979) and Phillips and Perron (1988) methods. The equations below represent the unit root statistics of ADF and P-P test:

$$\Delta y_t = \phi + \partial_t + \beta y_{t-1} + \sum_{i=1}^{m} \partial_i \Delta y_{t-i} + \varepsilon_t \quad (6)$$

$$\Delta y_{t-1} = \varnothing_0 + \tau_{t-1} + \varepsilon_t \quad (7)$$

In this context, Δy_t represents the first difference of the series y_t, ∂_t indicates the coefficient of a time period trend, m signifies the maximum length of the lagged endogenous parameter, ϑ_t refers to the parameter of the lagged first difference, and ε_i is the pure white noise error term.

However, these methods give wrong information about the stationarity properties when there are structural break problems in information (Perron, 1989). So, to clear up any confusion caused by any structural break in the series, we incorporated the DF-GLS examination (Elliot et al., 1992) in this case. It exhibits superior overall effectiveness in case of small sample size, surpassing the traditional Dickey-Fuller test (Baum, 2001; Vougas, 2007). Therefore, implementing all these tests can ensure the soundness of the ARDL methods (Raihan, 2024).

4.2. ARDL Method

Upon determining the integration level(s) of the series, suitable statistical techniques are employed to obtain conclusions. This paper used the ARDL (Pesaran et al., 2001) methodology, which is often more effective than other co-integration methods that are already out there. One of its notable benefits is that it does not necessitate substantial time series data, rendering it more appropriate for lower sample sizes in comparison to other co-integration approaches (Jama and Abdi, 2025; Abbas et al., 2024). The additional advantage of utilising the ARDL technique is its capability for predicting both the immediate and sustained effects of regressors on the parameter of concern (Shahid et al., 2021). A general-to-specialized modeling method is made possible by the ARDL paradigm, which meticulously encapsulates the data creation process by using the right number of lags. Furthermore, if none of the factors integrate to order 2 or higher, the ARDL structure can include elements with mixed orders of insertion (Garg et al., 2024). The long term simulation of ARDL model is given in equation (8):

$$\Delta LEF_t = \varphi_0 + \delta_1 LEFP_{t-1} + \delta_2 LGDP_{t-1} + \delta_3 LGE_{t-1} + \delta_4 LRE_{t-1} + \delta_5 LNRE_{t-1} + \delta_6 LURBA_{t-1} + \sum_{i=1}^{k} \varphi_1 \Delta LEF_{t-1} + \sum_{i=1}^{k} \varphi_2 \Delta LGDP_{t-1} + \sum_{i=1}^{k} \varphi_3 \Delta LGE_{t-1} + \sum_{i=1}^{k} \varphi_4 \Delta LRE_{t-1} + \sum_{i=1}^{k} \varphi_5 \Delta LNRE_{t-1} + \sum_{i=1}^{k} \varphi_6 \Delta LURBA_{t-1} + \varepsilon_t \quad (8)$$

This study aims to maintain consistency of k across variables such as GDP, GE, NRE, RE, and URBA after preparing the dataset, ensuring coherence throughout the study period. This is because; once the model has been adjusted for insufficient data or lags, inaccurate information or uneven time frames may result in a smaller k (Xuan, 2025).

Equations (9) and (10) denote the alternative hypothesis (H_A) and the null hypothesis (H_0). We compare the available evidence for cointegration H_A with the H_0, asserting the existence of cointegration. If the F-statistic is above both the lower and upper threshold values, the H_0 cannot be accepted.

$$H_0 = \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 \quad (9)$$

$$H_A \neq \varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq \varphi_5 \neq \varphi_6 \quad (10)$$

Moreover, the error correction model (ECM) was adopted after identifying the associations over time. Equation (11) illustrates the incorporation of the ECM into the ARDL method.

$$\Delta LEF_{t-i} + \varphi_0 + \sum_{i=1}^{k} \delta_1 \Delta LEF_{t-i} + \sum_{i=1}^{k} \delta_2 \Delta LGDP_{t-i} + \sum_{i=1}^{k} \delta_3 \Delta LGE_{t-i} + \sum_{i=1}^{k} \delta_4 \Delta LRE_{t-i} + \sum_{i=1}^{k} \delta_5 \Delta LNRE_{t-i} + \sum_{i=1}^{k} \delta_6 \Delta LURBA_{t-i} + ¥ECT_{t-i} + \varepsilon_t \quad (11)$$

4.3. Robustness Check (FMOLS, DOLS, CCR)

Multiple economic models have been employed to assess the consistency among parameters. The study implemented different approaches such as the FMOLS (Phillips and Hansen 1990), DOLS (Stock and Watson 1993), and CCR (Park, 1992) tests in Equation (8) to assess the accuracy and uniformity of the ARDL conclusions. These methods work especially well for solving the econometric problems that come up with non-stationary data, like endogeneity and serial correlation, which are common in monetary time series assessment (Zhou et al., 2022; Iormom et al., 2024; Usman et al., 2020). Firstly, the FMOLS approach transforms the OLS estimations to address serial correlation and endogeneity concerns. It offers an advanced two-step estimating method to rectify these problems (Ishola, 2025). Furthermore, FMOLS guarantees that the computed coefficients precisely represent the fundamental connections over time (Chiou et al., 2025). The DOLS estimates offer a reliable assessment of statistical significance by evaluating the endogenous variable against exogenous indices in levels, leads, and lags, serving as an effective approach for tackling different orders of integration (Dogan and Seker, 2016). Conversely, the main favor of DOLS projection is its capacity to accommodate the diverse order integration of different variables inside the cointegrated structure (Raihan and Tuspekova, 2022). Finally, the CCR method deals with the endogeneity that comes from the connection withinn the cointegrating equation's mistakes and the new features of the stochastic regressor over time (Park, 1992; Helmy, 2025).

4.4. Diagnostic Test

Moreover, multiple diagnostic procedures, like the Jarque-Bera test for residual normality, the Breusch-Godfrey test for serial correlation, the Lagrange multiplier test for detecting serial correlation, the Breusch-Pagan-Godfrey test for heteroskedasticity, and the CUSUM and CUSUMSQ tests for model rigidity, were employed to confirm the ARDL accomplishments.

5. RESULTS AND DISCUSSION

5.1. Descriptive Statistics

Table 2, which contains 33 observations, presents a comprehensive breakdown of the factors researched in the article. It indicates that each factor has a positive mean, except for LEF and LGE. The GDP variable has the greatest mean value of 6.4862 and the greatest median value of 6.1951. Furthermore, the findings show negligible standard deviations for all variables during the specified time frame, indicating a normal distribution of the data and making the dataset suitable for regression analysis. All of the variables, with the exception of LGDP, LGE, and LURBA, seem to exhibit normalcy as pointed out by the negative skewness values of the factors. The experiment employed kurtosis to assess whether the series displayed a robust or weaker tail in comparison to a normal distribution. We also used the Jarque-Bera normality analysis to confirm that every parameter in the study followed a normal distribution. This data necessitate the execution of a correlation analysis among the variables.

5.2. Unit Root Test

Verifying data stationarity is the preliminary stage in any time-series analysis. Table 3 presents the anticipated unit root assessments (ADF, P-P, and DF-GLS). The ADF findings demonstrate that the URBA variable is stationary at I(0) and significant at 5%, whereas LEF, LGDP, LGE, LRE, and LNRE are stationary at I(1) and significant at 1%. The P-P approach also shows that the LURBA factor stays the same at I(0) and is significant at the 5% threshold, while the other variables show a degree of integration I(1) and are significant at the 1% level. The results of the DF-GLS approach corroborate those of the ADF and PP assessments; however, the LURBA component is significant at the 1% level. Overall, our results show that the series is stationary at mixed levels of integration, I(0) or I(1), indicating that the ARDL limits cointegration approach can be adopted in this research.

5.3. ARDL Bound Test

The inquiry adopted the ARDL bound testing approach to check the presence of cointegration among the variables. Table 4 displays the findings, indicating that the anticipated value of the F-test exceeds both limit values. It affirms the presence of a sustained correlation between these elements, both at the lower and upper bounds. It also demonstrate that the calculated F-statistic value (4.8971) is higher than the critical upper limits at the 10%, 5%, 2.5%, and 1% significance levels in both order zero and one. This means the null hypothesis is not true, and there is likely to a sustained association among the factors. Such features additionally force the structure to prioritize its response to standard stochastic interruptions. Therefore, we can conclude that variations in all of these variables impact the EF in Bangladesh.

5.4. ARDL Short and Long Run Result

Once we determine their cointegration through the ARDL bound assessment process, we can evaluate their long-term partnership. Table 5 presents the short and long term impacts of LGDP, LGE, LRE, LNRE, and LURBA on LEF in Bangladesh using the dynamic ARDL paradigm. The findings indicate that the ecological condition in Bangladesh deteriorates due to GDP expansion, urbanization, and the adoption of NRE over time.

The data in Table 5 demonstrate that an additional 1% in LGDP will diminish the environmental quality by 0.315% in the short term and 0.276% in the long term. Economic expansion adversely affects the natural habitat health of Bangladesh, as evidenced by its significance at the 5% level in the short term and the 1% over time. Numerous investigations, such as Saliba et al. (2022) in China, Javed et al. (2024) in G-7 economies, Ali and Ali (2024) within

Table 2: Summary statistics

Characteristics	LEF	LGDP	LGE	LRE	LNRE	LURB
Mean	−0.66146	6.486239	−0.68638	3.813799	4.157437	3.322289
Median	−0.67335	6.195197	−0.73837	3.883624	4.179465	3.314804
Maximum	−0.37412	7.900794	−0.37412	4.391953	4.391953	3.82218
Minimum	−1.04928	5.606041	−0.94328	3.218876	3.798325	2.986237
Std. Dev.	1.043045	0.739403	0.100073	0.347924	0.174411	0.219351
Skewness	−0.0745	0.591929	0.342519	−0.33994	−0.51454	0.092774
Kurtosis	1.614902	2.007803	1.99095	1.817024	2.234934	1.670325
Jarque−Bera	2.650343	3.280716	2.046238	2.558127	2.260444	2.478388
Probability	0.265757	0.193911	0.359472	0.278298	0.322962	0.289617
Sum	−21.8282	214.0459	−22.654	125.8554	137.1954	109.6355
Sum Sq. Dev.	1.848497	17.47789	0.627855	3.913809	0.962288	1.53968
Observations	33	33	33	33	33	33

Table 3: Unit root test

Variables	ADF		P-P		DF-GLS		Decision
	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)	
LEF	−0.888	−7.136***	−0.582	−6.801***	−1.082	−7.021***	I (1)
LGDP	2.578	−3.870***	2.081	−3.691***	1.982	−4.018***	I (1)
LGE	−2.075	−6.299***	−1.982	−5.981***	0.687	−4.291***	I (1)
LRE	−2.181	−5.554***	−1.092	−4.098***	−1.092	−3.980***	I (1)
LNRE	1.029	−5.263***	1.592	−6.035***	1.570	−5.982***	I (1)
LURBA	−3.087**	−6.019***	−3.091**	−5.098***	−3.988***	−6.573***	I (1)

Table 4: ARDL bound test

Critical	Test statistics	Value	K	
bounds	F statistics	4.8971	5	
Significance level				
Critical bounds	10%	5%	2.50%	1%
I (0)	2.08	2.39	2.7	3.06
I (1)	3	3.38	3.73	4.15

Table 5: ARDL short-run and long-run results

Variables	LR	SR
LGDP	0.276*** (0.0257)	
LGE	−1.874*** (0.0591)	
LRE	−1.052*** (0.1025)	
LNRE	0.875** (0.0125)	
LURBA	0.384*** (0.0264)	
D.LGDP		0.315** (0.0243)
D.LGE		−0.838*** (0.0321)
D.LRE		−0.314** (0.2472)
D.LNRE		0.451*** (0.4172)
D.LURBA		0.118*** (0.0751)
ECT (speed adjustment)		−0.359*** (0.2168)
Constant		4.877*** (0.8719)
R-square	0.895	

Bangladesh, Gow and Saba (2024) within Bangladesh, Murshed et al. (2022) in Bangladesh corroborate these results. Due to rapid industrialization, nations have increased financial operations in various areas such as production, energy, transportation, and farming to achieve economic growth (Boluk and Karaman, 2024). These actions, however, demand significantly more energy and exert strain on the natural world (Udemba, 2020). On the other hand, Ridwan et al. (2024a) and Raihan et al. (2024) revealed that GDP growth is not harmful for the ecosystem, rather it reduces damage to the environment. Furthermore, Ridwan et al. (2024b) assert that GDP contributes to the alleviation of ecological stresses over time in the USA.

Subsequently, the findings reveal that government effectiveness and EF has a favorable link indicating that stability in the government can reduce the loss of biodiversity. Specifically, a 1% increment in LGE will cause an 8.38% in short run and 1.874% in long run fall of environmental damage in Bangladesh. In both cases the result is significant at 1 % level of significance. This outcome is corroborated by Wang et al. (2024) in BRICS regions, Feng et al. (2024) within China, Han et al. (2024) in some selected areas and Abid (2016) within Africa. Legislative and regulatory excellence delivers a crucial part in promoting equitable expansion and aiding in ecosystem protection, which has sparked interest in a governance system (Mehlum et al., 2006). In a resource-abundant economy, insufficient administration and institutions impede progress. Nevertheless, robust organizational and legislative structures would foster activities, enabling different institutions to implement policies that exert greater stress on the environment and yield longer-term results (Hussain and Dogan, 2021). Governmental quality reduces transaction expenses and enhances fiscal effectiveness. Consequently, legislation and regulation safeguard the natural environment (Qing et al., 2024).

The calculated coefficients for LRE demonstrate an obvious opposite relationship with LEF, suggesting that the deployment of renewable energies may benefit environmental health in Bangladesh. This indicates a 1.052% long-term decrease and a 0.314% short-term decline in LEF, which corresponds to a 1% increment in LRE. The adoption of RE benefits the environment by reducing GHG emissions and pollutants (Said, 2024; Cui et al., 2022; Wu et al., 2024). Moreover, alternative electricity resources are abundant and naturally vanished, enabling them essential for current and upcoming RE requirement while substantially minimizing GHG releases (Bashir et al., 2025; Behera et al., 2025). In the flip side, the inverse and statistically significant sides of LNRE coefficients demonstrate that a rise in LNRE in both time periods has a detrimental consequence on natural world. Particularly, a 1% spike in LNRE will cause a 0.875% upsurge in long run and 0.451% increment in short run of LEF in Bangladesh. This result is supported by Aslan et al. (2024), Niu et al. (2024), Kongkuah (2024), and Ajide and Mesagan (2022). This is unsurprising given that the fossil fuels utilized to generate these forms of energy are the main drivers of GHG emissions (Noor et al., 2024). Nonrenewable energy sources, due to their limitations and unsustainability, intensify temperature rise and climate change by boosting GHG emissions (El Khoury et al., 2025). In order to promote prosperous economies, authorities should increase domestic financing in renewable energies and draw in greener innovations (Ridwan et al., 2024c).

Similarly, the data suggests that URBA increases the pressure on Bangladesh's ecological situation in both terms. A 1% increment in LURBA will result in a 0.384% overtime and a 0.118% immediate spike in LEF, with results significant at the 1% threshold for both time frames. This conclusion is not entirely surprising, given that most individuals in Bangladesh migrate to urban areas seeking better living circumstances, employment opportunities, and superior infrastructure, among other reasons

(Borsha et al., 2024; Lipi and Hasan, 2021). These operations primarily rely on the adoption of energy, natural gas, and coal, which ultimately deteriorate ecosystem health (Sampene et al., 2022; Jin et al., 2024). However, limited research, like that of Lin et al. (2017), Rafiq et al. (2016), Adebayo and Ullah (2024), and Khan et al. (2024), demonstrated that URBA does not adversely affect ecological degradation. The ECT value is −0.359 and is significant at the 1% level, supporting the evidence of persistent integration. It demonstrates that fluctuations in the independent variables are associated with approximately 35.9% of long-term alterations to the EF. Additionally, the long-run evaluation R2 value is 0.895, indicating that the generated regression model aligns exceptionally well with the data.

5.5. Robustness Result

In this work, we assessed the efficacy of the ARDL model adopting the FMOLS, DOLS, and CCR techniques in Table 6. For each 1% enhancement in the LGDP, the FMOLS, DOLS, and CCR models typically stimulate the LEF by 0.413%, 0.316%, and 0.297%, respectively. This coefficient is aligned with the outcomes of the ARDL computation. It is significant at the 1% level in FMOLS, 10% in DOLS, and 5% in the CCR estimate. Conversely, the significant and positive results for LGE corroborate the ARDL findings. The LRE variable exhibits an inverse relationship with LEF across the three estimations, being significant at the 1% threshold in FMOLS and DOLS, while in CCR, it is significant at the 5% level. The conclusions of the FMOLS, DOLS, and CCR further demonstrate the strength of the ARDL estimation for the LNRE and LURBA variables. Moreover, a 1% increases in LNRE results in a 0.528%, 0.692%, and 0.731% rise in LEF, respectively. The outcome is significant at 1% in FMOLS and at 5% level in DOLS and CCR estimations. A 1% boost in LURBA for each model results in an average increase in LEF of 0.398%, 0.401%, and 0.280%, respectively. It is significant at 5% level for FMOLS and CCR, but for DOLS it is at 10% threshold. In summary, the aforementioned evidence demonstrates the reliability of the findings derived from the ARDL short- and long-run approach.

Table 6: Robustness check

Variables	FMOLS	DOLS	CCR
LGDP	0.413***	0.316*	0.297**
	(0.0618)	(0.0126)	(0.0286)
LGE	−1.918***	−0.861***	−1.043***
	(0.0391)	(0.0162)	(0.1072)
LRE	−0.701***	−0.825***	−1.061**
	(0.1891)	(0.1304)	(0.0781)
LNRE	0.528***	0.692**	0.731**
	(0.2031)	(0.3651)	(0.1628)
LURBA	0.398**	0.401*	0.280**
	(0.1083)	(0.2017)	(0.1056)
C	4.077***	5.0413***	4.434***
	(1.2108)	(0.1686)	(0.1692)

5.6. Diagnostic Test

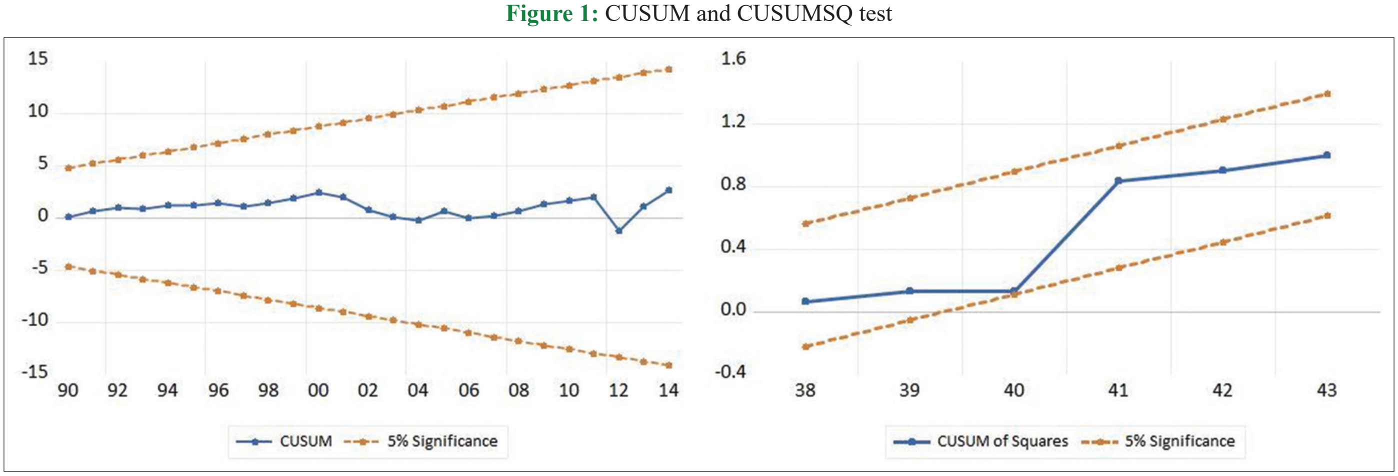
Potential difficulties, like outliers, multicollinearity, heteroscedasticity, and endogeneity concerning internal regressors, could arise. Therefore, we must verify the accurate validation of the ARDL model's error correction. Table 7 displays the findings of multiple diagnostic assessments to evaluate the validity and accuracy of the calculated equation from the ARDL structure. These outcomes indicate the lackings of serial correlation, non-normality, or heteroscedasticity.

Table 7: Results of diagnostic test

Diagnostic tests	Coefficient	P-value	Decision
Jarque-Bera test	0.45693	0.1062	Residuals are normally distributed
Lagrange Multiplier test	0.29372	0.1135	No serial correlation exits
Breusch-Pagan-Godfrey test	0.18751	0.2051	No heteroscedasticity exists

Additionally, the conclusions of the CUSUM and CUSUM-SQ assessments, presented in Figure 1, further enhance the reliability of the framework. Given that the statistical line remains wihtin the critical limits at the 5% significance thresholds, we can infer that the coefficients derived from the ARDL methods are reliable. Therefore, the comprehensive outcomes of all these tests show that the model has no identified faults that could compromise its reliability.

Figure 1: CUSUM and CUSUMSQ test



6. CONCLUSION AND POLICY IMPLICATION

This inquiry uses time series data from 1995 to 2021 to empirically examine the connection among urbanization, RE and NRE usage, GDP expansion, governmental efficacy, and EF of Bangladesh. This study investigated several unit root evaluations to assess the stationarity of the factors while tackling any methodological issues. Using the ARDL-bound testing technique, we performed a broad assessment of the connections within the endogenous and independent factors in both the long and short term. We also employ other estimators like FMOLS, DOLS, and CCR to evaluate the validity of the ARDL conclusions over both time periods. The results of the ARDL model indicate a robust correlation between renewable energy utilization, governmental efficacy, and EF, while GDP development, urbanization, and the adoption of non-renewable energy exhibit a significant negative influence in Bangladesh. It highlighted the advantages of green energy utilization and the establishment of effective governance for environmental sustainability. The results obtained suggest the potential integration of socio-economic aspects with the objectives of equitable growth and sustainable approaches into macroeconomic policies. The concordance of results from FMOLS, DOLS, and CCR with the ARDL technique further reinforced the study's conclusions. The study provides stakeholders and policymakers with valuable insights and a thorough comprehension of the variables influencing the ecological footprint in Bangladesh. To enhance resilience and prosperity in the region for the future, it establishes a framework for responsible decision-making by advocating policies that foster continuous economic growth and the conservation of biodiversity.

Policymakers in Bangladesh should implement multiple policy strategies to balance economic growth with energy consumption while protecting the environment and supporting sustainable development. The strong positive relationship between GDP growth rates and ecological footprint levels demands that economic planning incorporate environmental factors using green growth strategies and environmental taxes along with incentives for low-carbon business sectors. The negative correlation between government effectiveness and EF demonstrates the importance of building institutional governance through strict environmental regulation enforcement as well as improving regulatory compliance and enhancing inter-agency coordination. Governments can maximize sustainable energy advantages by directing investments toward renewable energy infrastructure while offering financial incentives and improving the integration of renewable energy into the power grid. Due to the harmful effects of non-renewable energy and urban growth on EF we need to shift away from fossil fuels by implementing progressive carbon pricing systems along with tougher emission regulations and adopting urban sustainability protocols that cover green construction standards and sustainable transit solutions. Bangladesh must build a strong environmental governance system and increase climate adaptation funding while embedding sustainability into national development plans to achieve lasting environmental resilience. The effectiveness of environmental sustainability goals and economic stability hinges on implementing a comprehensive policy mix.

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