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Estimating the impacts of economic globalization and natural resources on ecological footprints within the N-shaped EKC in the Next 11 economies

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The economic development of N-11 countries has been significantly influenced by the contributions of natural resources (NAT) and economic globalization (EG). These countries have been facing drastic environmental problems for several years. Hence, it is imperative to ascertain the environmental ramifications of natural resource extraction activities in the N-11 nations. In doing so, this study examines the impact of gross domestic product (GDP), EG, and NAT on ecological footprints (EF) within the time frame of 1971 to 2022 in the group of N-11 countries. After verifying the cross-sectional dependence, this work found the integration of all variables at first difference. To provide short and long run econometric results; this study utilizes cross sectional autoregressive distributed lag (CS-ARDL). The findings indicate that the presence of NAT rent has a detrimental impact (0.03%) on the ecological quality within the N-11 nations. Moreover, it can be argued that both EG and GDP exhibit environmentally sustainable characteristics over an extended period by (0.03% and − 3.12%) respectively. This study does not provide evidence for the presence of an N-shaped Environmental Kuznets Curve (EKC) in the N-11 nations. Based on the findings, a policy recommendation is proposed for the nations in question. These countries must immediately implement and enforce robust environmental laws while fostering a heightened sense of environmental consciousness. It is imperative for emerging economies to increase their investments to explore and adopt efficient technologies in various economic sectors, including mining.

Keywords GDP, Economic globalization, Natural resources, CS-ARDL, EKC, N-11 nations

The role of natural resources (NAT) has a fundamental position in the economic sector of any country. Proper use of NAT can contribute to the economic development of any nation. The next eleven (N-11) are developing countries with abundant NAT. These countries are expected to lead in economic development in near future[1]. These nations maintain a high degree of economic growth (GDP) and industrialization. These macroeconomics features have increased the energy demand which is mostly coming from non-renewable sources[2]. Therefore, non-renewable NAT are increasing GDP and contaminating the environmental quality[3]. Several studies have documented those NAT are an essential element to increase GDP[4]. Fiscal progress enables improving infrastructure, decreases poverty, and provides maximum employment opportunities. However, this economic development can have adverse impacts on environmental quality. To achieve rapid GDP, several nations are compromising their NAT and contaminating their climatic quality[5]. The work of Ref.[6] confirmed that NAT degrades the environment in BRICS. Additionally Ref.[7], documented that NAT and GDP are increasing the ecological footprints (EF) in 45 nations[8]. presented that NAT increase greenhouse gases (GHGs). Therefore, the dependency of N-11 nations on NAT can be an obstacle to sustainable progress. However, the works of Refs.[9,10] have shown that GDP is environmentally friendly, and the environmental Kuznets curve (EKC) exists. Similarly Ref.[11], also confirmed that GDP reduces carbon emissions.

Reference[12] showed that GDP is destroying the climate in 181 economies and EKC is valid only in 21 countries. Hence, it is important to highlight the impact of NAT on the environment by including the GDP of the next eleven (N-11) states. Along with economic growth, the role of globalization has been compulsory.

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Economic globalization (EG) has amplified the trade and production process. This process has increased energy consumption, which is degrading the climatic quality (Erdogan et al. 2020). During the year 2018, primary energy consumption was amplified by 2.9% (Petrolium 2019). This energy consumption has increased the GHGs almost by 65%. N-11 countries are consuming excessive oil, coal, and gas. Hence, the EG helps to enhance GDP, this growth further helps to install additional industrial units. These industries further degrade the environmental quality. From this perspective, it is obvious that EG can impact the environment in N-11 countries.

The Next Eleven (N-11) countries—Egypt, Bangladesh, Indonesia, Mexico, Iran, Nigeria, the Philippines, Pakistan, South Korea, Vietnam, and Turkey—constitute a coalition of nations with harmonized fiscal policies designed to attain sustainable financial goals, as acknowledged by the International Monetary Fund. These nations are anticipated to ascend as leaders worldwide in economic development in the forthcoming years. Nevertheless, they presently encounter considerable environmental issues, ranking among the most polluted countries in terms of climate. In response to international pressure and national desires for healthier environments, these nations are striving to mitigate climate-related pollution[13]. According to Fig. 1, it can be noted that EF has been continuously growing from the year 1971. Currently, these countries are facing drastic climatic variability. Therefore, it becomes essential to investigate the factors of climate variability so that effective environmental policy can be formulated. This work adopts the EF by global footprint network. This index provides a comprehensive measure of the depletion of NAT by human footprints[13]. In other words, this index is showing the statistics about the available biocapacity and its depletion by the human being. Therefore, Ecological Footprints (EF) provide a detailed measure of environmental degradation (Aslan et al. 2018). N-11 countries are consuming their NAT, and the EF is increasing continuously. This condition highlights the importance of this work to evaluate the role of NAT in environmental degradation. Figure 1 shows the trends of EF in N-11 nations.

The research underscores the significance of sustainable economic development in N-11 nations, highlighting the adverse environmental consequences of extracting natural resources. It corresponds with multiple Sustainable Development Goals, notably advancing sustainable production and consumption, along with climate action. Recommendations for stringent environmental legislation and expenditure on efficient technology highlight the necessity for a harmonious approach to economic advancement and ecological conservation. Therefore, the primary intent of this inquiry is to find out the prime place of NAT for environmental misery in N-11 countries. This work also includes the EG, so that the role of international trade and collaboration can be evaluated for a sustainable environment in N-11 nations. Additionally, this work investigates the context of the N-shaped EKC of NAT and EG. As a result, this work answers the following questions for N-11 nations. (1) Do NAT rent degrade the climatic quality in N-11 nations? (2) Can EG help to improve air quality? (3) Does the N-shaped EKC exist in N-11 republics?

The remaining sections are organized as follows: The 2nd part provides the theoretical foundation of this work, the 3rd part presents background literature, 4th section is about the model and methodology. 4th part is about findings and their conversation. The 5th part summarizes the findings and discusses policy outcomes for N-11 countries.

Theoretical framework

This section elaborates on how NAT impact environmental quality in relation to GDP and EG. EG increases trade, and this activity further impacts climatic quality in two ways (Scale impact and composition impact). The scale effect measures the production activity due to international trade[14]. International trade enhances the production of goods and services[15]. As a result, this economic activity further affects the environmental quality. The composition effect defines the linkages between the composition of products and international trade. It defines the factors that affect the formulation of dirty technologies in emerging nations and cleaner technologies in the advanced world (Copeland and Taylor 2013). The countries with flexible environmental policies allow

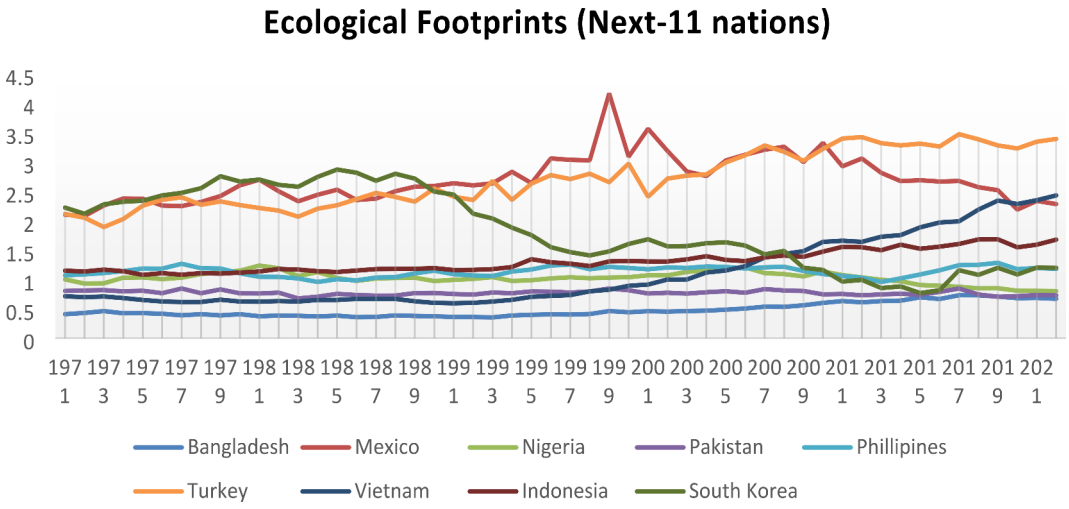

Fig. 1. Trends of ecological footprints in N-11 states.

traditional technologies in the economic sector. This procedure defines the way dirty technologies are shifted toward developing nations. Hence, this activity degrades the climatic feature[16].

This study aims to investigate the effects of GDP on the environment over the notion of the N-shaped EKC recognized by[17]. Past studies[18,19] have found the upturned U-shaped relationship among GDP and climatic degradation. However, N-shaped EKC holds the view that this U-shaped EKC does not stay the same in the long run. In fact, after some time, increased GDP starts to contaminate the environmental quality[20]. According to the scholars, N-shaped EKC arises due to the scale impact because the scale effect dominates the composition effect due to ineffective use of efficient technologies[21].

Literature review

The association of NAT and environmental humiliation is not consistent because of competing views. Several studies have established that NAT helps to improve GDP, especially in resource-rich nations. On the other hand, some studies found that NAT degrades climatic excellence. A study by Ref.[22] examined the connection between GDP, NAT, and climatic degradation. The annual data is analyzed by the scholars from 1990 to 2014 and found long-run linkages in Algeria[23]. found that NAT and GDP are linked with environmental quality in Pakistan. According to Ref.[24] Germany, Japan, and the USA ought to enhance investments in renewable energy to mitigate the vulnerability of these sources to disruptions, thereby formulating policies that promote sustainable development and energy security. France and the United Kingdom both can achieve energy security by maintaining their sustainable energy policy. The findings of Ref.[25] showed that the load capacity curve theory is not valid in European countries. Natural resource depletion undermines environmental sustainability. Green investments and technologies enhance environmental quality and can thus facilitate effective climate action. The report advocates targeted measures to attain the Sustainable Development Goals, specifically emphasizing goal 13. The work of Ref.[26] found that economic expansion and trade liberalization detrimentally affect environmental sustainability, although favorable developments in investment enhance the environment in both nations. Adverse investment shocks negatively impact the environment in the United States, but not in France. This paper presents comprehensive sustainable development policies for the USA and France. For Turkiye[27], indicates that renewable energy sources are inadequate for Turkiye, highlighting the distinctiveness of this study. Our recent discoveries enable policymakers to implement measures for environmental sustainability. Given Turkiye's regional characteristics necessitating energy security, it should augment expenditures in renewable energy technologies. Empirical data indicates that clean energy technology will advance if politicians endorse human capital development. The findings of Ref.[28] showed the essential importance of managing mineral resource rents to attain the Sustainable Development Goals in Brazil. Furthermore, augmenting investment in renewable energy sources and shifting towards low-carbon energy can facilitate sustainable growth in Brazil. The Brazilian government ought to cease mineral extraction, prioritize low-carbon energy use, and safeguard the environment by implementing stringent rules on foreign investment activities.

In contrast[29], examined the yearly data (1970–2015) of the USA, and found that human capital and NAT are environmentally friendly[30]. conducted a study for BRICS. They analyzed the data from 1992 to 2016 and found that NAT are lowering EF in BRICS. They also validated a U-shaped correlation among GDP and environmental degradation[5]. analyzed the data of Pakistan and discovered that clean energy and NAT are refining air quality in Pakistan. Their study validated the EKC in Pakistan. That study found a negative role of EG on climatic quality[31]. also found the same results for Mena nations from 1980 to 2016. The work of[32] probed the impacts of EG on the environment in ASEAN nations. Their work showed that EG is not environmentally friendly and the EKC is valid between EG and EF. The work of[33] applied a dual adjustment method to explore the connection between climate and globalization in Turkey. Their work found a direct link between globalization and EF. On the other side[34], discovered that globalization put no impact on EF in Malaysia.

According to Ref.[35], the load capacity curve (LCF) is applicable in Turkey. Furthermore, whereas trade openness threatens environmental sustainability, the consumption of renewable energy and industrial competitiveness enhance environmental quality. According to Ref.[36], Investments in clean energy research and development, enhance environmental quality. Conversely, it has been determined that investments in research and development related to fossil fuels and urbanism diminish the load capacity factor[37]. Empirical research indicates that positive shocks to NAT adversely affect the LCF, whereas negative alterations in NAT enhance environmental well-being. However, the enduring effect of a unit plus shock in NAT diminishes the LCF more significantly than a unit negative shock amplifies it. The findings also illustrate a 'U-shaped' relationship between growth in income and ecological well-being, thereby validating the load capability curve (LCC) hypothesis. Moreover, the results indicate that renewable energy utilization and enhancement of human capital improve environmental quality. The work of Ref.[38] demonstrate the insufficiency of municipal solid waste transformation in EU nations and underscores the positive impact of human capital and clean energy sources on improving environmental quality. This study presents definitive proof that natural resources facilitate environmental corruption[39]. found that the GDP, NAT, and primary consumption of energy exacerbate environmental degradation. The results suggest that employment and environmental efforts cannot achieve success concurrently. To address this challenge, initiatives should focus on sustainable production methods, including renewable energy sources[40]. showed that although economic expansion, trade liberalization, and competitiveness deteriorate environmental quality, clean energy and human capital enhance environmental sustainability.

Reference[41] analyzed the linkages of RE, globalization, and climatic quality. They used the pool mean group (PMG) technique and showed that RE is improving the climate. Nevertheless[42], discovered the N-shaped linkages amongst GDP and CO2 emissions in the Chinese region. Hence, the previous studies have provided uneven results with limited areas. According to the EKC theory, the connection between GDP and environmental quality is inverted U-shaped[43]. However, the N-shaped theory maintains that U-shaped linkages are not stable over time. Instead, over time and after a certain income level, this link may become direct[44]. This condition happens when the

scale impact dominates the structure effect. This might be due to the shortage of resources to allocate for improved industrial structure. NAT, globalization, and environmental quality are interlinked. This link is justifiable due to several factors, including natural resource mining and its management in industries. In this regard, this study investigates the linkages of EG, NAT, and environmental degradation. From the above discussion, this work verifies the findings of previous research studies. The previous work has presented dissimilar findings. These contradictory findings may be due to the different mining of resources and organizational policies. Some studies found a fundamental impact of globalization in expanding or receding EF. Thus, this study not only examines the connection of globalization, NAT, and the environment but also examines the relationship with GDP, its Quadratic, and cubical form to check the N-shaped EKC in the presence of EG. While past research work mostly explored the U-shaped linkages for most economies. Moreover, most of the research has taken international trade as a substitute for globalization. Few studies also took the globalization index, but the current study took EG in N-11 countries[45]. asserted that natural resources facilitate economic growth, hence refuting the resource curse argument. The interplay between natural assets and geopolitical risk obstructs economic progress, hence corroborating the natural resource curse theory as influenced by geopolitical conflicts. Furthermore, the results indicate that capital investment and technical innovation enhance global economic production[46]. presented a matrix of policy recommendations to attain SDG-13 (Climate Action) in BRICST nations. Policymakers should promote sustainable energy and technological advancements to reduce pollution. Policymakers must consider the adverse environmental impact of reduced economic policy uncertainty. Consequently, specific actions must be implemented throughout the period of economic policy uncertainty.

Model and methodology

This study aims to examine the effect of NAT, EG, GDP, and EF in N-11 nations. For empirical investigation, this work has taken the yearly data for 1971–2022, except for Iran and Egypt because of unavailability of data of EF. The data for NAT and GDP are obtained from the world bank and the data for EG and EF have been obtained from the KOF institute and the global footprint network. Table 1 shows the variable's detail and origins.

Per capita economic growth denotes the rise in a nation's GDP divided by its total population, illustrating the average GDP produced per individual and signifying overall economic well-being. NAT denotes the revenue derived from the extraction and use of natural resources, which can profoundly influence economic development while potentially causing environmental degradation. Economic globalization is the growing interdependence of economies via investment, trade, and technology, affecting growth trends and resource allocation among countries. Ecological footprints assess the environmental effect of a population by quantifying the natural resources and ecosystem services necessary to support their consumption and waste, hence indicating the long-term viability of their economic activity. Figure 2 shows the graphical form of descriptive statistics (scatter plot).

The following model is analyzed:

$$lnEF_t = F\left(EG_{it}, G_{it}, Gs_{it}, Gq_{it}, NAT_{it}\right) \tag{1}$$

$$lnEF_t = \beta_0 + \beta_1 lnEG_{it} + \beta_2 lnG_{it} + \beta_3 lnGs_{it} + \beta_4 lnGq_{it} + \beta_5 lnNAT_{it} + \varepsilon_{it} \tag{2}$$

In these equations, EF, EG, G, Gs, Gq, and NAT represent the EFs, EG, GDP, GDP square, GDP cube, and NAT.

Cross-sectional dependence test

The cross-sectional dependence (CD) test is the first step in the technique. The reliance of panel data nations is revealed by the CD test. CD is employed to ascertain whether the error components of a regression model exhibit correlation across various units or observations. This ensures the reliability of inference and estimate in panel data analysis, as neglecting such reliance can result in skewed outcomes. The econometric methods used to calculate cointegration and long-run coefficient values can be refined with the help of these test findings. Pesaran's use of CD in this piece is an ongoing development. (2015). So, here is the corresponding solution for the evaluation:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\partial_{ij}^{t}\right) \tag{3}$$

N stand for cross-section sand T for time, respectively. ∂_{ij}^{t} is an association of errors.

Parameters	Sign	Unit	Origins
Ecological footprints	EF	Gha per person	Global footprint Network (GFN)
Natural resource rents	NAT	% Of GDP	World data indicators (WDI)
Gross domestic product	GDP	constant US dollars	WDI
Gross domestic product square	GDP S	constant US dollars	WDI
Gross domestic product cubic	GDP Q	constant US dollars	WDI
Economic globalization	EG	0-100 index	KOF

Table 1. Variables their detail and origins.

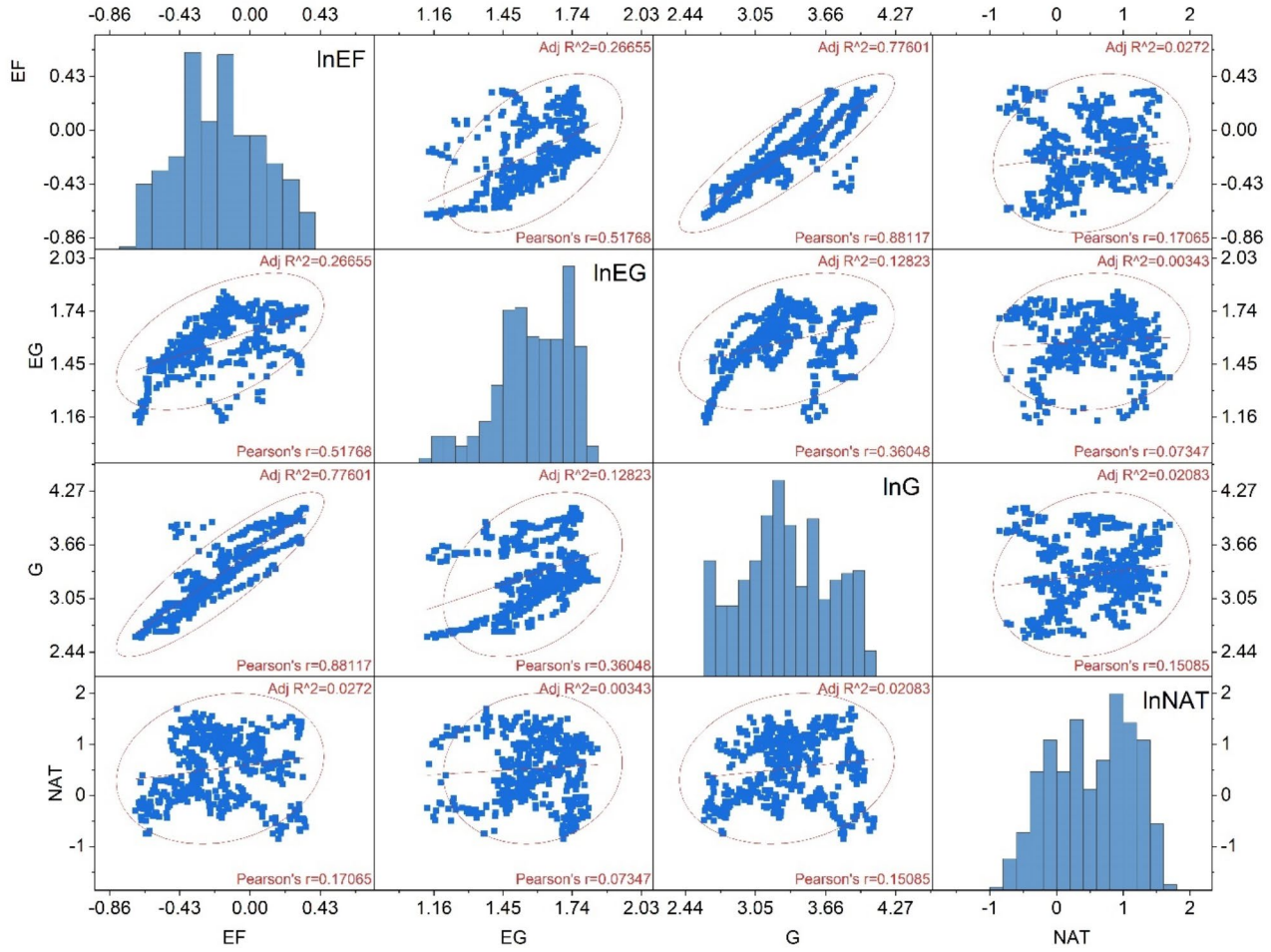

Fig. 2. Scatter plot descriptive statistics.

Slope homogeneity test

Slope homogeneity tests evaluate the consistency of the connection between both dependent and independent variables across various groups or units, hence verifying the reliability and applicability of model estimates throughout the whole dataset. The panel data concept was initially presented by[47]. The expression for this test is as under:

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - K}{\sqrt{2\,K}}\right) \tag{4}$$

$$\tilde{\Delta}_{\text{adj}} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - E\,(\tilde{Z}_{iT})}{\sqrt{var\,(\tilde{Z}_{iT})}}\right) \tag{5}$$

Unit Root test

If the evidence points to the existence of CD, then second-generation stationarity investigations are essential. The cross-sectionally augmented IPS (CIPS) and cross-sectionally augmented DF (CAF) unit root studies are two helpful instruments for this. CIPS and CADF unit root tests are crucial as they enable researchers to identify stationarity in panel data while considering cross-sectional dependence, thereby augmenting the robustness of time series analysis in multi-dimensional datasets. The research' findings will be used to determine the order of EF, RE, FIG, GDP, and NAT.

Co-integration test

The objective of this study is to investigate the co-integration relationship between EFs, renewable energy, financial globalization, GDP, and NAT. The Westerlund cointegration test is important as it facilitates the identification of cointegration in panel data while considering any CD amongst the units. This improves the

dependability of long-term relationship evaluations between variables, rendering it especially beneficial in economic and financial research where such correlations are essential[48]. The present study employs the work for this particular objective[49]. The efficacy of the test is demonstrated by its ability to yield reliable and resilient outcomes even when confronted with the presence of confounding variables in the dataset. The following equations are relevant to this examination:

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{\partial_i^!}{SE\partial_i^!} \tag{6}$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\partial_i^!}{\partial_i^!(1)} \tag{7}$$

$$P_t = \frac{\partial^!}{SE\left(\partial^!\right)} \tag{8}$$

$$\partial^! = \frac{P_a}{T} \tag{9}$$

$\partial^! = \frac{P_a}{T}$ represents the ratio of correction per year.

Short-run and long-run analysis

The CS-ARDL model was selected for this investigation because it effectively analyzes dynamic interactions among variables, considering both short-run and long-run impacts. This methodology is also advantageous for addressing data that may display cross-sectional dependence, as is frequently observed in N-11 nations, where financial and environmental problems are interconnected. The application of CS-ARDL enables the study to accurately elucidate the intricate linkages among natural resources, economic globalization, and ecological footprints, hence strengthening the validity of the results. This methodology facilitates subtle insights, enhancing the generalizability of results across comparable emerging economies by offering a thorough perspective on the temporal interactions of various variables. Nonetheless, generalizability may be affected by the specific circumstances of the N-11 countries; thus, conclusions should be evaluated about regional disparities and special environmental variables. Therefore, to obtain short and long-run values, the study opts method developed for the CS-ARDL by (Chudik and Pesaran, 2015) rather than the more common FMOLS or DOLS. Reliable findings can still be obtained through the application of the Coefficient Stationarity AR Distributed Lag Model (CS-ARDL) approach even in the presence of the CD (cross-sectional dependence) in the data. This exceeds the capabilities of initial-generation experiments. So, here is the corresponding solution for the evaluation:

$$\Delta EF_{i,t} = \varnothing_i + \sum_{I=0}^{p_w}\varnothing_{ij}\Delta EF_{i,t-1} + \sum_{I=0}^{p_z}\varnothing_{ij}AEV_{i,t-I} + \sum_{I=0}^{p_z}\varnothing_{ij}Z_{i,t-I} + \epsilon_{i,t} \tag{10}$$

$Z_i = (\Delta EF_t\ AEV_t)$ represent the cross-section medians where AEV shows a set of instructive variables.

Robustness check test

This study persists in utilizing the enhanced mean group (AMG), FMOLS, and DOLS techniques as a means of cross-checking the results and ensuring their reliability. This analysis accounts for CD issues and variation[50].

Results and discussions

All relevant test outcomes are summarized here. All scores are displayed in increasing order for this reason. This implies that the long-run, short-run, co-integration, and cross-sectional reliance tests are available, as well as the stability check test. Initially, it is important to examine the panel statistics for signs of CD. The outcomes are shown in Table 2.

Panel data of EF, EG, NAT, and GDP is having cross-sectional dependence in N-11 nations. This means that any shift in one country will impact on the trends in other countries in N-11. This correlation could potentially be attributed to the implementation of comparable economic policies. The identified CD likely arises from the interrelation of global economic systems and environmental policies, wherein alterations in one variable can substantially affect the others. This interconnectedness illustrates the complex relationships among the variables, requiring a further analytical approach. The subsequent procedure involves assessing the homogeneity of slopes in the panel data. The findings are presented in Table 3.

Variables	T Statistics
EF	23.10***
EG	47.83***
NAT	11.49***
GDP	47.85***

Table 2. Cross-sectional dependence test. ***Explains the level of significance at 1%.

	Numerical value	Numerical *P* value
Delta	2.70***	0.00
adj	2.88***	0.00

Table 3. Slope test. ***Describes the level of significance at 1%.

Variable	CADF test		CIPS	
	At Level	1st difference	At level	1st difference
$lnEF_t$	− 2.72	− 3.94***	− 2.64	− 6.38***
$lnEG_t$	− 2.78	− 5.40***	− 2.62	− 6.18***
$lnNAT_t$	− 2.61	− 5.19***	− 2.75	− 6.12***
$lnGDP_t$	− 2.72	− 3.94***	− 1.96	− 4.73***

Table 4. Unit root test. ***Explain the level of significance at 1%.

Stat	Value	Z value	*P* value
G_t	− 2.92***	− 2.32	0.01
G_a	− 16.59***	− 2.52	0.00
P_t	− 6.14***	− 2.28	0.01
P_a	− 6.44**	− 2.25	0.03

Table 5. Westerlund test. ***,**Explain the level of significance at 1% and 5% respectively.

Table 3's p-values indicate that the alternative hypothesis is true. As a result, there are issues with variation in panel statistics. The findings of the slope homogeneity test provide substantial support for the null hypothesis of slope homogeneity for the parameters EF, EG, NAT, and GDP, since both Delta and adjusted statistics exhibit elevated values and p-values of 0.00. This indicates that the correlations among these variables are inconsistent across various units or contexts, suggesting that the influence of EG, NAT, and GDP on EF varies considerably, which is essential for customized policy interventions. As a result, the panel data's unit root can be located using the second-generation stationarity test. This research uses the CIPS and CADF two-unit root analyses for this reason. The results are tabulated in Table 4.

The panel data of EFs, EG, NAT, and GDP is static at 1(I). None of the variables is static at the level. This indicates that although the variables display unit roots at the level, they demonstrate a stable relationship over time when differenced, which is crucial for reliable econometric modeling and comprehending long-term interactions among these elements. This outcome is guiding us to move forwards to find out the co-integration among the panel data of N-11 nations. For this reason, this work utilizes the[49] test and the outcomes are in Table 5.

Table 5 shows that the panel data of EF, EG, NAT, and G is strongly cointegrated in the long run. G_t, G_a, P_t, P_a values for group and panel are significant. This indicates that, despite single non-stationarity, the variables EF, EG, NAT, and GDP exhibit co-movement across time, signifying a shared stochastic tendency and underscoring the necessity of examining their interrelated dynamics in long-term analysis. This outcome is further making us conduct CS-ARDL to obtain the long and short-run coefficient values.

Table 6 shows the findings of CS-ARDL, according to which natural resource rents are not environmentally friendly. This means that income through NAT is contaminating the climatic quality. NAT can deteriorate environmental quality chiefly through overexploitation, resulting in habitat damage and loss of biodiversity as ecosystems are depleted. Pollution resulting from mineral extraction and processing, including extraction and fossil fuel manufacture, taints air, soil, and water, hence exacerbating harm to ecosystems. Furthermore, alterations in land use due to the conversion of natural landscapes for agricultural or industrial uses lead to soil erosion and the destruction of wildlife habitats, so upsetting ecological equilibrium. Ineffective management techniques intensify these problems, whilst resource exploitation leads to climate change, leading to harsh weather and modified ecosystems. To alleviate these effects, sustainable resource management strategies are crucial for safeguarding environmental quality. This result shows that N-11 countries have been using their NAT in an unsustainable manner. This finding is like the results of (Ahmad et al. 2020) who found NAT are contaminating the environment in China. On the other hand, this finding is not like the findings of[51] for Spain, Germany, France, the United Kingdom, and Italy. They found that NAT rent is environmentally friendly.

The role of EG in N-11 is good for the environment. This means that a 1% increase in EG will lower the EF by 0.03% in the long and short run. The result shows that N-11 states are following efficient policies to import improved technologies. EG can improve environmental quality through many ways, chiefly by enabling the transfer of superior technology and sustainable practices internationally. This interconnection enables nations to implement cleaner production techniques and effective resource management tactics, hence diminishing

Short run	Coefficient	ST ERROR	PROB
$\Delta\, lnEG_t$	− 0.03***	0.01	0.00
$\Delta\, lnNAT_t$	0.05***	0.01	0.00
$\Delta\, lnGDP_t$	− 0.08***	0.02	0.00
$\Delta\, lnGDPS_t$	2.02***	0.10	0.00
$\Delta\, lnGDPQ_t$	− 1.95***	0.02	0.00
Long Run			
$lnEG_t$	− 0.03***	0.01	0.00
$lnNAT_t$	0.03***	0.01	0.00
$lnGDP_t$	− 3.12***	0.05	0.00
$lnGDPS_t$	4.06***	0.20	0.00
$lnGDPQ_t$	− 0.77***	0.12	0.00
ECM	− 0.79***	0.07	0.00

Table 6. CS-ARDL. ***,**Describe the level of significance at 1% and 5%, respectively.

environmental impacts. Moreover, globalization frequently results in the formulation of international environmental norms, prompting corporations to embrace sustainable practices and enhancing overall accountability. Heightened worldwide consciousness regarding environmental concerns stimulates support for sustainability efforts, compelling governments to enforce more stringent environmental regulations. Moreover, globalization entices foreign investment in sustainable solutions, bolstering initiatives in energy efficiency and conservation. Ultimately, the demand for sustainable products in international markets compels enterprises to innovate and minimize their environmental impact. These elements collectively demonstrate how globalization of economy can enhance environmental quality and promote sustainable development. The work of Refs.[52,53] also found that EG is improving the climate in G7 nations. This work cannot find the existence of N-shaped EKC in N-11 countries. GDP is negatively linked with EFs and GDP square and GDP cube are positively and negatively associated with EF. In the Next Eleven (N-11) countries, economic progress, as shown by GDP, frequently coincides with enhanced ecological footprints owing to augmented investments in environmentally friendly technologies and infrastructure. As GDP increases, these nations can adopt more effective resource management strategies and impose more stringent environmental restrictions. Moreover, elevated income levels generally foster increased public knowledge and interest in sustainable behaviors, culminating in a net decrease in ecological effect. The correlation between GDP growth and increasing ecological footprints indicates that although economic expansion initially enhances efficiency and sustainability, surpassing a specific limit results in a significant escalation in the use of resources and pollution levels. This suggests that elevated economic activity may result in increased environmental deterioration, when heightened output and consumption surpass the advantages of technical progress and regulatory measures. The cubic of GDP and the reduction of ecological footprints indicate that, at elevated levels of economic growth, the advantages of innovation and environmentally friendly methods become progressively more substantial. This suggests that when economies expand, they may more efficiently embrace advanced technology and cleaner energy sources, leading to reduced consumption of resources and emissions. Thus, the relationship underscores the possibility for economies to separate growth from environmental damage upon attaining a specific degree of maturity and stability. In other words, currently, GDP is indirectly related to EF but after some time this link will be direct and GDP will contaminate the climate, and again after reaching some specific time, the GDP will start to improve the environment. The work of Ref.[54] found an N-shaped association at the provincial level in China. The error correction term (ECT) is significant and negative at the 1% level. This means that disequilibrium in EFs will be corrected by 7.9% annually. The significance of the prob value shows the model's stability.

Robustness check

To assess the reliability and validity of the analysis, this research Also utilizes the completely modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and augmented mean group (AMG) estimators. The tests employed in this study also account for the presence of cross-sectional dependence on the panel data, thereby ensuring the reliability and robustness of the obtained outcomes. The results of these tests are presented in Table 7.

The FMOLS, DOLS, and AMG test results validate the authenticity of the findings of CS-ARDL. EG and GDP are environmentally friendly and N-shaped EKC cannot be validated in the panel of N-11 countries.

Conclusion and policy recommendations

Rapid GDP and EG have increased the consumption of NAT in resources poor countries of N-11. This research scrutinizes the effects of NAT, EG, and GDP on EFs over the years 1971–2022 in N-11 republics. For empirical investigation, the Next-generation methodology is applied. The existence of cross-sectional dependence makes this work adopt second-generation unit root tests. All the variables co-integrated at first difference. The Westerlund test confirmed the strong correlation among the panel data. The findings of the CS-ARDL method cannot find the N-shaped EKC in the existence of NAT and EG in N-11 nations. This finding is contributing

Variable	AMG	FMOLS	DOLS
$lnEG_t$	− 0.48**	− 0.55***	− 0.67***
$lnNAT_t$	0.02***	0.04***	0.07**
$lnGDP_t$	− 0.13***	− 0.77***	− 1.12***
$lnGDPS_t$	0.31***	0.09***	0.14***
$lnGDPQ_t$	− 0.37***	− 0.03***	− 0.05***

Table 7. Robustness check. **,***Describes the level of significance at 1%.

to literature significantly. The role of NAT rent is not environmentally friendly because NAT is contributing to environmental degradation. This outcome may be due to the unsustainable use of NAT in N-11 countries. The industrial output of these NAT is creating more EF. This finding is also showing that N-11 countries are not adopting efficient technologies in their output process. Moreover, EG is helping these economies to sustain their development. This finding shows that N-11 nations are implementing efficient policies to stop the imports of dirty technologies into industries. This work also shows that GDP is helping to curb EFs, but its square term is again increasing the EF. Moreover, its cube term starts to improve the environment in the long run. This outcome supports the existence of N-shaped EKC in N-11 countries.

These findings shed light on critical policy consideration for N-11 states. These countries must implement effective strategies to achieve sustainable development. For this purpose, governments should provide incentives to the public and private sectors to install environmentally friendly technologies. Environmental awareness should be spread to make people environmentally friendly. Public awareness along with environmental regulations can work superbly for a cleaner environment because people will follow the environmental regulations willingly. This work considers the N-11 countries for empirical analysis, future research work can include other groups of emerging countries. Moreover, other factors of financial globalization, government stability, and income inequality can be included in the model. Other econometric methods can also be used for effective policy making in other groups of countries.

The policy implications for the N-11 nations should prioritize the promotion of sustainable economic growth through investments in clean technologies and energy from renewable sources sources, aiming to divorce GDP growth from the impact on the environment. Policymakers ought to enforce more stringent environmental regulations and promote sustainable practices inside industry to reduce pollution and resource exhaustion. Educational initiatives and public awareness initiatives can cultivate an attitude of sustainability among individuals and enterprises. Moreover, augmenting international collaboration can promote knowledge exchange and access to financing for sustainable initiatives. Moreover, establishing comprehensive monitoring and evaluation systems will allow these countries to evaluate the efficacy of their environmental initiatives and implement data-informed modifications. Promoting sustainable planning and construction of infrastructure can alleviate the ecological consequences of fast urbanization. Ultimately, cultivating public-private partnerships will optimize resources and innovation to attain collective sustainability objectives, so establishing a more robust economic future.

Limitations and future research directions

This study's limitations encompass possible data inconsistencies among N-11 nations and the difficulty in distinguishing the effects of specific regulations on ecological footprints. Future research ought to concentrate on longitudinal evaluations to enhance comprehension of the dynamic interplay between economic expansion and environmental quality, alongside case studies that investigate successful initiatives for sustainability within these nations. Moreover, examining the influence of social variables and public involvement in promoting sustainable practices may yield profound insights into attaining enduring ecological objectives.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

Q.J., wrote the original manuscript. Z.Z., collected the data. S.X., and K.S., analyzed the data. T.Z., did analysis of the results. R.C., and H.W. wrote the conclusion and policy implications.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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