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Exploring the Linkages between ICT, Energy-Economic Growth in Mitigating Ecological Footprints: Evidence from D – 8 Member States

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ABSTRACT

The member states of D-8 organization are facing various environmental challenges. There is a rapid environmental contamination caused by the usage of fossil fuels for energy. As a result, developed and developing nations alike are implementing a variety of approaches to address environmental issues. Therefore, the aim of this research is to examine the interrelationships among information and communication technologies (ICT), natural resource rent (NNR), economic growth, green technology innovation (GTI), green finance (GFI), and ecological footprints (EFP) in the D – 8 countries. Reliable methodologies and annual data covering the period from 1995 to 2022 were employed to present the results. To find out how the thing changes over short and long periods, we used a method called cross-sectional augmented autoregressive distributed lag (CS-ARDL). The results showed that the EKC theory is true in this specific area. Depletion of natural resources and economic expansion both contribute to an increased ecological footprint. Green finance, information and communication technologies innovations, and technological advancements all contribute to the reduction of the ecological footprints. A unidirectional causal relationship was established between economic growth, green finance, ecological footprints, and information and communication technologies via the D-H causality test. The present study incorporates novel insights from the D – 8 countries into the extant body of knowledge concerning the origins of environmental contamination. Furthermore, this research offers a standard by which policymakers and government agencies in these industries can assess their investments in information and communication technologies green finance, and environmentally friendly technologies, in an effort to reduce environmental contamination.

Keywords: Economic Growth, Green Innovation Technology, Green Finance, Information and Communication Technology
JEL Classifications: F6, O4

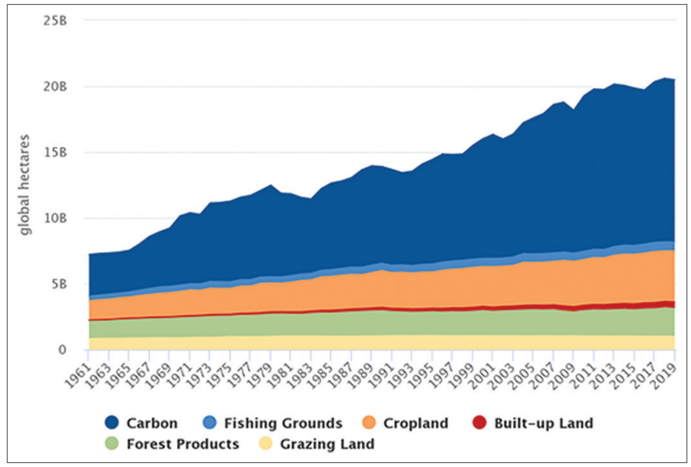
1. INTRODUCTION

Recent climate change negotiations, known as “COP26, the Glasgow Climate Pact,” convened in November 2021 in the United Kingdom, emphasized the criticality of decelerating universal climate modification. Therefore, all countries should strengthen their mitigation plans to engage in the global endeavor to decrease ecological pollution actively. The Glasgow Climate Agreement makes plans and rules for quickly lessening ecological footprints. The inquiry is centered on the D – 8 countries: Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan and Turkey. Turkey is at the forefront of economic development among these countries, with Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan and Turkey also experiencing tremendous economic expansion. This growing economy necessitates energy consumption, and now, the Turkey economy is the highest in the consumption of power in the area (Akhayere et al., 2023; Mukhtarov et al., 2022). The economic development activities of the D – 8 Countries heavily rely on traditional fossil fuels, posing a significant risk to the region's environmental sustainability (Canbay, 2021). Despite the D – 8 Countries' progress in economic growth, their environmental sustainability record could have been more satisfactory (Majeed and Asghar, 2021). Therefore, it is of the utmost importance to identify the factors that have an effect on ecological footprints in these states and to devise a rule agenda in order to reduce the likelihood of this risk occurring.

Globally, the mean ecological footprints per individual was roughly 2.58 hectares (Global Footprint Network, 2022). This finding indicates that an ecological footprints deficit of 1.1 hectares exists on a global scale (Sahoo and Sethi, 2021). Recently, the ecological footprints have emerged as a viable alternative to quantify environmental pollution (Majeed, 2020; Ansari et al., 2020; Hussain et al., 2022). The advancement of technology and environmental laws are considered necessary preconditions for achieving the final stage of the EKC hypothesis. This is even though each of the variables listed above impacts the environment directly or indirectly (Yin et al., 2015). It is further asserted that green technological innovation regulates the interrelationships among environmental quality factors and that green innovation-supported commercial activities contribute to environmental quality Zhang and Li (2020) and its immediate effects. Ecological damage is mitigated, mainly through promoting energy efficiency and utilizing renewable energy sources, when energy sector-specific innovations are effectively financed (Hou et al., 2023; Nasim et al., 2023; Sahoo et al., 2024). Particularly in developing countries, access to costly environmental technologies is unattainable due to financial constraints. High-income developing countries (emerging economies) are afforded access to the financial system, enabling them to procure the necessary funds for environmental technology. On the other hand, poor growing countries still have to keep a production system based on fossil fuels. People are arguing about whether making things for businesses to sell, which can harm the environment indirectly, or making it worse. In the 1990s, people began to study connections between economic growth and shortage of resources in nature. Grossman and Krueger (1991) developed the Kuznets Curve Hypothesis in this context. The Environmental Kuznets Curve proposes a reversed U-shaped link between GDP per capita and environmental deprivation. In the early stages of economic growth, people virtually have no ecological consciousness. Energy is indeed an essential factor in the process of industry and manufacturing. Figure 1 illustrates how the world's ecological footprints have increased dramatically since 1961 as a result of industrial and economic expansion.

Energy consumption is a substantial determinant of economic expansion in most countries. As a result, peak economies use old-style energy bases such as coal oil fossil and natural gas to satisfy the level of demand. Fossil fuel, one of the traditional

Figure 1: World's ecological footprints



energy sources is impacting ecological footprints (Li et al., 2023; Li et al., 2022; Qing et al., 2024). There is more-exploring the interaction between ecological footprints and green finance has turned into an original battleground among ecological experts. It is imperative to annotation that green finance is an investment plan that objects to support environmental maintenance (Kayani et al., 2023). Therefore, green finance provides a platform for private investors to pick up the slack inadequately filled by public expenditures (Muganyi et al., 2021). Knowing the impact of natural resource rent on ecological footprints is necessary because in terms of environmental factors, D – 8 countries have abundant resources that promote economic development. In most countries the ecological footprints are in deficit if natural resource rent is used up rashly. According to Danish and Ulucak (2020) large-scale economic expansion leads to greater exploitation of natural resource rent, undermining environmental sustainability in the process. Information and communication technologies for economic growth are another concept related to environmental sustainability on the rise. Nowadays, information and communication technologies have become an important factor in promoting human welfare and economic growth. According to some studies, the rise of information and communication technologies is negatively correlated with environmental contamination; it helps improve quality of life (Caglar et al., 2021; Jie et al., 2023). Therefore, evaluating the effects of information and communication technologies on ecological footprints is vital because development in this area has begun to surge into high gear across D – 8 countries. Under the circumstances mentioned above, this study explored how economic growth, natural resource rent, information and communication technologies, and so on interact over time in an environmental worldview. How should emerging economies like the D – 8 countries maintain ecological sustainability while pushing for economic development?

In principle, this study represents a secure contribution to environmental research because: (1) ecological footprints are often used as the standard for measuring all different kinds of environmental smog. Yet existing studies have faulted the use of ecological footprints alone to define environmental smog. Part of the reason is that ecological footprints only includes a small portion of multifaceted environmental smog facing emerging economies (Majeed et al., 2021; Dogan et al., 2022; Addai et al., 2022). (2) These scholars are hopeful that this is an initial foray into incorporating variables including green finance, natural resource rent, green technology innovation and information and communication technologies in exploring countries such as the D – 8 countries under the EKC hypothesis. As a result, this study research in the writings by provided that practical proof about the way in which these variables are related to green smog among D – 8 countries. (3) This study used the latest, second generation sectional dependence test for CSD (Pesaran, 2015). To determine whether or not long-term interactions exist among the series, three different methods suggested by Kao (1999), Pedroni (2004); Westerlund (2007) were employed in analyzing this study. The present study continues with the CS-ARDL developed by Pesaran (2015) to estimate short and long term estimators. this research utilized contemporary techniques such as Pesaran (2007) common correlated effect means group estimator and the augmented mean group method of (Eberhardt and Teal, 2020), all used to test for robustness with respect to CS-ARDL. Finally, the novel Dumitrescu and Hurlin (2012) was used to test for causality between the series.

2. LITERATURE REVIEW

This study segment investigates the correlation between ecological footprints, information and communication technologies, natural resource rent, green technology innovation, green finance, and information and communication technologies concerning the foundational principles of literature.

2.1. Green Finance and Ecological Footprint

There are a variety of internal and external reasons that have formed the unique techniques that countries take to record green finance and ecological footprints. It is amazing to observe these approaches. We must continue to aspire for constructive change while valuing their diversity. However, most scholarly articles center on the beneficial impact of green finance in mitigating resource depletion through the promotion of nonrenewable resource utilization while examining the fundamental factors contributing to the intensifying environmental strain (Murshed, 2021; Nazir et al., 2018). Furthermore, the environmental Kuznets (EKC) hypothesis demonstrates the significance of green finance in maintaining ecological stability (Tariq and Hassan, 2023). The strategy aims to simplify the implementation of sponsoring green funds and improve the efficiency and effectiveness of the company's regulations. Further, over the past 2 years, rapid green efforts have surged to fulfill Sustainable Development Goal standards. These initiatives have focused on offshore wind and solar photovoltaic, highlighting how financial advancements through green strategic techniques contribute to the decarburization of economies and enable sustainability (Khezri et al., 2022; Rafique et al., 2021). Maintaining a focus on environmentally responsible policies and practices is essential in light of the growing environmental issues we face. In a fortunate turn of events, the area of environmental policy and research has acknowledged the vital need and has been concentrating on creating measures that promote ecological sustainability and global financial inclusion. As a result of these efforts, we may all progress towards a more environmentally friendly future. Nawaz et al. (2021) point out that green finance is an overarching term that focuses on financial investment in support of sustainability efforts and ecologically friendly policies. According to Sampene et al. (2023), there is a poor correlation between sustainable finance and South Asian countries 'environmental footprint. Similarly, Meo and Abd Karim (2022) evaluated how green finance affected ecological preservation in the top ten green finance -investing economies. This is because their results indicate an indirect proportionality between green finance and ecological footprints. According to their research, green finance is a helpful tactic for boosting the environment.

2.2. Information and Communication Technologies and Ecological Footprint

Over the past 30 years, the information and communication technologies industry has seen intense competition. Businesses, governments, and consumers have all increased their use of data. Fryer (2019) identifies two potential applications of information and communication technologies in mitigating environmental pollution: information and communication technologies can do this by using renewables and better energy efficiency. (2) From an economic perspective, information and communication technologies can reduce emissions. Researchers researching the environment must deliver more precise conclusions on the relationship between information and communication technologies and ecological footprints. According to research, the high energy consumption accompanying information and communication technologies raises ecological footprints levels. Environmental pollution is the task of today's world. Although we've successfully reduced our carbon footprint, advanced technologies are needed to take this further. We can create a more explicit and healthier planet with technology. Enhanced technologies provide an additional glimmer of optimism regarding the attainment of sustainability (Ahmed et al., 2017). The environmental impact of OBOR countries is influenced by global trade and access to capital. The findings obtained through the panel valuation technique are compelling. The data indicates that financial expansion and ecological impact share a counter relationship. These results have high practical significance and could serve as an impetus for policymakers to pursue prudent development policies. Aydin and Turan (2020) discovered a similar point of view when they analyzed the impact on their ecological footprints through EKC theory, including trade policies, financial openness, and economic stability. Our recent research on green credit, securities, insurance, and investments has conclusively proven that these environmentally friendly measures significantly decrease harmful atmosphere emissions. As long as we can adopt these measures, human lifestyles will become a force for positive change in the ecology. Yet even suggesting that green living could become a mainstream lifestyle still requires too much planning. Now, the time has come to move forward, and we hope you will join us in our efforts for a more sustainable world. Youssef et al. (2020) have shown that clean energy is a significant factor in the information and communication technologies industry. There are currently 4.67 billion active internet users worldwide, and information and communication technologies offers quick solutions for all types of enterprises through massive communication infrastructures. Internet use and cellular subscriptions on mobile devices have been used as proxies for information and communication technologies (Khan et al., 2022).

2.3. Natural Resource Rent and Ecological Footprint

Environmental scientists have lately investigated the relationship between ecological footprints and natural resource rent (Saqib et al., 2023; Du and Wang, 2023; Tu et al., 2022; Roy, 2024). Ahmad et al. (2020) used data from 1984 to 2016 to examine the relationship between natural resource rent and ecological footprints among rising nations. The research findings suggest that a higher use of natural resource rent results in an environmental deficit. However, the negative ecological footprints of natural resource rent can be mitigated by implementing current technological innovations in natural resource usage. Likewise, Erdoğan et al. (2021) stated that sub-Saharan African economies' overreliance on natural resource rent for economic progress leads to increased environmental pollution. According to Ibrahim and Ajide (2021), ecological footprints in the economies of the BRICS countries was influenced by natural resource rent, financial development, and regulatory quality. Furthermore, Kongbuamai et al. (2020) suggested that the effective use of natural resource rent might be central to environmental sustainability.

2.4. Green Technology Innovations and Ecological Footprint

It is projected that green technological innovation would significantly affect pollution reduction. The host countries' environmental sustainability has risen due to technological innovation working with ecological regulation to reduce pollution. Several investigations have been carried out to examine the connection between environmental quality and green technology innovation advancement. Researchers discovered that technological progress is essential in reducing carbon emissions. Also, their comparison study found that the Eastern region is much more capable than other parts of integrating innovations and environmentally friendly solutions. Some scholars are closely examining the impact of "green innovation" on environmental conditions. Researchers continue to debate whether technological innovations benefit or damage our environment. But their research needs to lead them to a firm conclusion. For example, the first group of researchers reached such findings: There is an unfavorable relationship between technological innovation and carbon emissions; Technological innovation plays a significant role in environmental quality improvement (Adebayo and Kirikkaleli 2021). Balsalobre-Lorente et al. (2018) examine the correlation between green energy, technical advancement, and environmental quality in the European Union using a dataset from 1985 to 2016. Based on this research, there is a solid and distinct N-shaped association between the actual output and CO_2 emissions in the five leading economies of the EU. The report highlights the detrimental impact of carbon emissions on the environment and the economy, emphasizing the pressing need for immediate action. By acknowledging the connection between these factors, governments may implement suitable measures to mitigate CO_2 emissions and foster sustainable development (Akbar et al., 2025). Furthermore, trade lowers environmental quality, whereas renewable energy and technical progress raise it. Based on Fan and Hossain (2018) research in China and India, open trade could improve environmental quality and technical innovation.

2.5. Economic Growth and Ecological Footprint

Grossman and Krueger (1995) obtained evidence for the EKC hypothesis in their study on trade agreements and environmental contamination in North America. Environmental researchers have widely acknowledged and incorporated this idea into several research studies, yielding diverse findings about the Environmental Kuznets Curve (EKC). However, this study has made a noteworthy contribution to the existing literature (Abid, 2016; Boukhelkhal, 2022; Dam et al., 2024). Uddin et al. (2017) used panel data from 1991 to 2012 to examine the relationship between economic development and ecological footprints among 27 high CO_2 emissions. Their findings suggested that an expanding economy has larger ecological footprints. Similarly, Ahmed et al. (2019) used panel data from 1971 to 2014 to examine the relationship between economic growth and ecological footprints in Malaysia. According to their empirical research, economic growth leads to an increase in ecological footprints. According to research by Mrabet and Alsamara (2017) on change and ecological footprints in Qatar, economic growth has significant long-term effects on ecological footprints. An investigation on the effects of growth on the environment in Azerbaijan between 1992 and 2013 by Mikayilov et al. (2018) shows that environmental destruction result from economic growth.

3. RESEARCH METHODOLOGY

3.1. Overview of Variables and Data Source

The D-8 are the countries of Developing-8 Organization for Economic Cooperation. It is an organization aiming to improve the global economic standing of the member states. The panel data for the period 1995-2022 has been collected on D-8 member countries namely Bangladesh, Indonesia, Iran, Malaysia, Türkiye, Egypt, Pakistan, and Nigeria.

Panel data on ecological footprints was found from the Global Footprint Network. The WDI database created green finance, information and communication technologies, Economic growth, and natural resource rent indicators. The OECD database was used to develop green technology innovation. The chosen series' element of measurement, symbols, and databases is shown in Table 1.

3.2. Model Specification

The econometric technique used in this study is mathematically stated as Eq. (1): It is created on the EKC model and is reliable with earlier fictitious effort by (Haldar and Sethi 2022).

$$EFP_{it} = f(EG_{it}, GFI_{it}, GTI_{it}, ICT_{it}, NNR_{it}) \quad (1)$$

The natural logarithm was used to transform all chosen variables in order to improve the data series' sharpness and distribution. The research data's heteroskedasticity and autocorrelation concerns are helped by the series' natural logarithm transformation. Eq. (2) represents the ecological footprints' log-linear form.

$$lnEFP_{it} = \beta_0+\beta_1 lnEG_{it}+\beta_2 lnGFI_{it}+\beta_3 lnGTI_{it}+\beta_4 lnICT_{it}+\beta_5 lnNNR_{it}+\epsilon_{it} \quad (2)$$

Such are economics growth, green finance, green technology innovation, information and communication technologies, natural resource rent and ecological footprints coefficients. In denotes the series natural logarithm form, is the model's constant, denotes the error terms of the perfect. Also, I mean cross sections (Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan and Turkey.), and 't' shows the time of the research (1995-2022).

3.3. Descriptive Numerical Facts

Table 2 presents descriptive, correlational and variance inflation factor (VIF) analyses for the series considered in this study. The result shows the mean information for ecological footprints (1.47), economics growth (3457.402), green finance (30.21), green technology innovation (10.22), information and communication technologies (21.47), and natural resource rent (8.31). These findings suggest significant differences across the D – 8 countries in all the series looked at in this study. The study's findings also indicate that the selected series have a relatively high standard deviation. The following are the values for ecological footprints (1.301), economics growth (3227.78), green finance (26.74), green technology innovation (6.19), information and communication technologies (24.16), and natural resource rent (8.11). As a result of these findings, there is a strong likelihood that the variable under research exhibits heterogeneity. Additionally, the normality of the data structure was tested using statistics like kurtosis, Jarque-Bera, and probability tests, which further demonstrated that the research data sample is not customarily dispersed. The results of the bivariate correlation study are shown in Table 3. The results indicate that economic growth and information and communication technologies are positively correlated with ecological footprints. Furthermore, natural resource rent, green technology innovation, and green finance exhibit an inverse correlation with ecological footprints. This discovery illustrates that the correlation between ecological footprints and all series is feeble. The research ultimately employed the variance inflation test to assess the issue of multicollinearity. As shown in Table 4, the findings demonstrate that, contrary to what Kim (2019) claimed, the research exemplary deficiencies multicollinearity because both the mean and discrete VIF values are <10.

3.4. Econometrics Technique

3.4.1. Cross-sectional dependence (CD) test

The CD test is the first step in the process. It displays any interdependence between the countries. The test findings also provide a preview of the econometric methods that will be used to calculate cointegration and long-run coefficient values. With the application of CD, this work is continued by Pesaran (2015). The following mathematical formula:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N} \varphi_i \sum_{m=i+1}^{N} \partial_{im} \quad (3)$$

Equation (3) shows the time, the CSD in the panel (represented by N), and the correlation coefficient between the i and m units (represented by Pesaran [2015]).

3.4.2. Slope homogeneity test

The panel data nature was first suggested by Pesaran and Yamagata (2008). It can be written as follows mathematically:

Table 1: Justification of data

Indicators	Symbol	Nature	Measurement	Source
Ecological footprint	EFP	Dependent	Global Hectare per capita, EFP (gha)	GFN
Green finance	GFI	Independent	renewable consumption as a proxy for green finance is measured in kilotons (kt)	WDI
Information, communication and technology	ICT	Independent	Population % of individuals using internet	WDI
Economic growth	GDP	Independent	GDP per capita (constant 2010 USD)	WDI
Natural resource rent	NNR	Independent	Natural resource rent % GDP	WDI
Green technology innovations	GTI	Independent	.	OECD

Table 2: Summary of descriptive statistical data

Measures	EFP	EG	GFI	GTI	ICT	NNR
Mean	1.477157	3457.402	30.21692	10.22174	21.47624	8.313796
Median	0.845490	2236.205	27.86500	8.313800	11.70000	6.746440
Maximum	5.046300	12507.80	88.68000	40.40000	96.75140	34.77910
Minimum	0.084234	322.0870	0.440000	1.030000	0.000000	0.143922
standard deviation	1.301204	3227.780	26.74794	6.191503	24.16794	8.116293
Skewness	1.073669	1.281998	0.726937	2.109498	1.163939	1.249531
Kurtosis	2.767335	3.534233	2.487237	9.206296	3.262042	4.149554
Jarque-Bera	43.54177	64.02181	22.18231	525.6350	51.21839	70.62332
Probability	0.000000	0.000000	0.000015	0.000000	0.000000	0.000000
Sum	330.8832	774458.0	6768.590	2289.670	4810.677	1862.290
Sum Sq. Dev.	377.5682	2.32E+09	159545.8	8548.639	130252.0	14689.95
Observations	224	224	224	224	224	224

Source: Authors' findings with E-Views 10

Table 3: Correlation matrix

Variable	EFP	EG	GFI	GTI	ICT	NNR
EFP	1					
EG	0.7265	1				
GFI	−0.3013	−0.5000	1			
GTI	−0.2215	−0.8570	0.1772	1		
ICT	0.4568	0.6984	−0.3870	−0.1138	1	
NNR	−0.2459	−0.0204	−0.1641	0.1398	−0.0123	1

Source: Authors' findings with E-Views 10

Table 4: Variance inflation factor analysis (VIF)

Variable	VIF	I/VIF
EG	2.25	0.4449
GFI	1.97	0.5079
GTI	1.44	0.6921
ICT	1.08	0.9294
NNR	1.07	0.9344
Mean VIF	1.56	

Source: Authors' findings with E-Views 10

$$\Delta = \sqrt{N\left(\frac{N^{-}S-K}{\sqrt{2K}}\right)} \quad (4)$$

$$\tilde{\Delta}adj = \sqrt{N}\left(\frac{N^{-}\widetilde{S}-E\left(\tilde{Z}\,it\right)}{\sqrt{var\left(\tilde{Z}\,it\right)}}\right) \quad (5)$$

3.4.3. Unit root tests

The performance of second-generation unit root tests is crucial if the presence of CD is confirmed within the data. The cross-sectional augmented IPS (CIPS) and cross-sectional enhanced CADF unit root tests were taken into consideration for this. These exams will assess how well ecological footprints, economic growth, green finance, green technology innovation, natural resource rent, and information and communication technologies were integrated in that order.

3.4.4. Test panel cointegration

The co-integration approach developed by (Pedroni, 2004) explores the cointegration relationship between the series by analyzing whether or not the residual value component of the equation is stable. This method's null hypothesis (H_0) is that the series does not exhibit co-integration. Co-integration test is formally represented as Equation. (6) in (Pedroni, 2004):

$$\hat{\varepsilon}_{it} = \rho_i \hat{\varepsilon}_{it-1} + \sum_{j=1}^{k} \varphi_{ik} \Delta\hat{\varepsilon}_{it-k} + v_{it} \quad (6)$$

The cross section dependency and heterogeneity in the research series were also analyses using (Westerlund, 2007) the co-integration technique. There is no co-integration in the error-correction term among the series, according to the null hypothesis (H_0) of this method. The mathematical expressions for this test are:

$$G_t = \frac{1}{N}\sum_{i=1}^{N} \frac{n_i}{S.E\left(n_i\right)} \quad (7)$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N} \frac{Tn_i}{1-\sum_{j=1}^{k} n_{ij}} \quad (8)$$

It is mathematically computed that the panel co-integration method statistical is

$$P_t = \frac{n_i}{S.E\left(n_i\right)} \quad (9)$$

$$P_a = Tn_i \quad (10)$$

3.4.5. Longrun estimation models

The study used Chudik and Pesaran (2015) CS-ARDL to evaluate the short- and long-term estimators. The presentation of this method (CS-ARDL) delivers healthier outcomes when compared to other valuation methods, such as the pooled mean group (PMG), and the estimates are more reliable. The following can be shown mathematically:

$$\Delta EFP_{i,t} = \varnothing_i + \sum_{I=0}^{p\omega} \varnothing_{ij} \Delta EFP_{i,t-1} + \sum_{I=0}^{pz} \varnothing_{ij} \Delta AEV_{i,t-1} + \sum_{I=0}^{pz} \varnothing_{ij} \Delta Z_{i,t-1} + \epsilon_{i,t} \quad (11)$$

3.4.6. Robustness checked valuation

The augmented mean group (AMG), FMOLS, and DOLS procedures were still used to cross-check the results and verify their reliability. Because they address the difficulties of CSD and heterogeneity, these tests are reliable (Eberhardt and Teal, 2020).

3.4.7. Causality analysis

The study used the contemporary Granger causality test developed by Dumitrescu and Hurlin (2012) to look at the dynamic relationships between series. This strategy aids in addressing the potential for cross section dependency and whether the study model includes slope variability. The Dumitrescu and Hurlin (D-H) granger causality test's null hypothesis is that there is no causal link between the variables. The model's causal relationship, on the other hand, is the alternative theory. The mathematical expression for the D-H non-causality test is given in equation 12:

$$Y_{it} = \alpha_i + \sum_{M-1}^{M} \gamma_i^m \,, Y_{I(m-t)} + \sum_{M-1}^{M} \delta_i^m \,, Z_{I(m-t)} \quad (12)$$

4. RESULTS AND DISCUSSION

4.1. Cross-Sectional Dependency and Slope Homogeneity Test Result

To examine cross-sectional dependency among the chosen series, three cross - section dependency tests were used in this research. Table 5 shows the outcomes of the cross - section dependency test. The test outcomes confirmed the rejection of the null hypothesis of cross - section dependency existence among the variable's cross section at a threshold for significance of 1%. As a consequence of this, this investigation can arrange that the D – 8 countries are

Table 5: Summary of the CSD findings

Series	Breusch–Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM
lnEFP	223.3717***	26.10765***	25.95950***
lnEG	597.1258***	76.05263***	75.90449***
lnGFI	332.4498***	40.68382***	40.53567***
lnGTI	70.26674***	5.648131***	5.499983***
lnICT	600.6162***	76.51906***	76.37092***
lnNNR	225.0299***	26.32922***	26.18108***

Source: Authors' findings with E-Views 10

Table 6: Summary of the SHT

Measures	Value	P-value
Delta	4.071***	0.000
Adj	4.854***	0.000

Source: Authors' findings with E-Views 10

Table 7: Summary of unit root test

Variable	CADF test		CIPS test	
	1 (0)	1 (1)	1 (0)	1 (1)
LnEFP	20.8276	97.1844***	−0.56306	−8.56566***
LnEG	5.40030	56.9500***	2.77076	−5.15373***
LnGFI	2.87456	29.4463**	3.94133	6.36925***
LnGTI	51.1375***		4.61915***	
LnICT	50.1135***		−4.39949***	
LnNNR	19.3862	79.1388***	−0.94826	−0.29972***

***=1%, **=5% and *=10% significance level
Source: Authors' findings with E-Views 10

interrelated in economic growth, information and communication technologies, natural resource rent, green finance and green innovation technology. Analyzing the degree of stationarity among the set of data under examination is the following phase in the study's model. Table 6 also includes the outcomes of the slope homogeneity test, which show that heterogeneity does exist for the D – 8 countries and that the null hypothesis of the slope homogeneity test is rejected. Additionally, the findings imply that the approach for assessing the cross - section dependency and heterogeneity in the next phases of the study is workable.

4.2. Unit Roots Test

Testing the stationarity level and integration order between the research series is crucial after solving the difficult of CSD. Analyzing the stationarity of the variables is critical when investigating panel pane data. Existing literature shows that non-stationarity in research data might result in flawed and inconsistent findings (Huang et al., 2022; Haldar and Sethi, 2022). This study used the CADF and CIPS tests, two of the greatest recent second-generation unit root tests, to look at the stationarity of the series. Table 7 demonstrates that (lnGIT, lnICT) was level and steady. But following the first difference, all of the contenders' series became stationary 1(1). A long-term co-integration of the series utilized in this research can be assessed using this approach.

4.3. Panel Cointegartion Test

In this study, we proved that the long-term connection among these series existed by using three methods. The results of the co-integration test are in Table 8. The Pedroni (2004) co-integration test's 6 out of 11 results show they don't support the zero guess, suggesting that it seems like these series might not be combined. The possible results are judged by the Westerlund (2007) co-integration method, used two bites and two-panel stats. Table 8 shows that both kinds of classifications (Gt and Ga) are good for statistics. They have a very important level of 1%. The findings of Kao (1999)about co-integration also show a long term connection between the chosen series.

4.4. Long-Term and Short Results of CS ARDL Calculator

Estimates were made of the values of independent variables' long- and short-run coefficients. We used the CS-ARDL technique to do this, and Table 9 presents the results of CS-ARDL. It demonstrates that information and communication technologies and ecological footprint are not connected. Accordingly, a long-term 1% increase in information and communication technologies will result in a 0.0912% decrease in ecological footprint (Salahuddin et al., 2016; Mehmood et al., 2022; Wang et al., 2023). The interpretation of this finding can be supported by the supposition that information and communication technologies improve energy efficiency and savings via decreasing environmental pollution. Additionally, information and communication technologies promote businesses to incorporate cutting-edge technology into their operations, which lowers emissions. The long-run coefficients that were negative of green finance and green technology innovation are 0.001% and 0.04%, respectively, indicating that they do not correlate with ecological footprints (Yu et al., 2020; Sampene et al., 2023). By investing money in green production, companies are committing to using less-polluting technology in their production processes. The beneficial effects of GDP and natural resource rent on environmental quality are indicated by coefficient values of 0.09% and 0.02%, respectively, at a 1% significance level (Sampene et al., 2023; Naqvi et al., 2021; Mehmood, 2022). One explanation for these results is the presumption that the usage of natural resource rent would openly promote economic development, which would therefore reduce ecological integrity in these economies. The study agrees that when natural resource rent is present, it means there's less money for companies. This makes their change plans harder and causes waste of resources which affects the ongoing life of ecological footprints. The long-term results match up with the short-term figures.

4.5. Robustness Tests

In addition to performing the CS-ARDL, this work goes further to assess the reliability of the results. The FMOLS and DOLS tests are used for this purpose. The results of the robustness assessment, which confirm the CS-ARDL results, are offered in Table 10. This indicates that our conclusions are reliable and applicable to D – 8 countries. The empirical results from this investigation are presented graphically in Figure 2.

4.6. D-H Causality Method

The CS-ADRL method only gives short term and long-term guesses. So, these methods need to prove that there is a cause-and-effect relationship between the panels in panel data. We must think about the cause and effect in order to show investors and plan creators similar actions together. The relationship between

Table 8: Summary of co-integration test

(Pedroni 1999, 2004)					
Within Dimensions	**Statistic**	**Probability**	**Between dimensions**	**Statistic**	**Probability**
Panel v-statistic	−0.8103	0.79	Group rho-statistic	−2.7823	0.99
Panel rho-statistic	−0.0622	0.47	Group PP-statistic	−0.0451	0.48
Panel PP-statistic	−0.5323***	0.00	Group ADF-statistic	−8.5156***	0.00
Panel ADF-Statistic	−7.3877***	0.00			
Weighted panel v-statistics	−8.3327***	0.00			
Weighted panel rho-Statistic	0.9791***	0.83			
Weighted panel PP-Statistic	−11.5898***	0.00			
Weighted panel ADF-Statistic	−8.2392***	0.00			
ADF	(Kao 1999)		(Westerlund, 2007)	Z- Value	
	t–statistic	0.00	Gt	−3.901***	0.000
	−0.2714***		Ga	2.713	0.997
			Pt	−2.912***	0.002
			Pa	2.426	0.992

0.01 represents the level of significance
Authors' findings with E-Views 10

Table 9: Summary of the result of CS-ARDL

Variable	Coefficient	Standard error	P-value
Long run analysis			
lnEG	0.099732	0.020143	0.0000
lnGFI	−0.001001	0.023848	0.0000
lnGTI	−0.044317	0.011037	0.0001
lnICT	−0.012252	0.004639	0.0091
lnNNR	0.025413	0.011600	0.0300
Short run analysis			
COINTEQ01	−0.181845	0.007504	0.0002
lnEG	0.092919	0.002556	0.0000
lnGFI	−0.005624	0.001162	0.0168
lnGTI	−0.001462	0.000103	0.0008
lnICT	−0.004406	0.000194	0.0002
lnNNR	0.015164	0.000542	0.0001

Source: Authors' findings with E-Views 10

Table 10: Robustness check

Variables	AMG	FMOLS	DOLS
LnEG	0.7589***	0.1389***	0.0909**
LnGFI	−0.0182**	−0.1036***	−0.0492**
LnGTI	−0.1394***	−0.0759***	−0.0567**
LnICT	−0.1077***	−0.0272***	−0.0119***
LnNNR	0.0412**	0.0558**	0.0170**

***=1% & **=5 significance level
Source: Authors' findings with E-Views 10

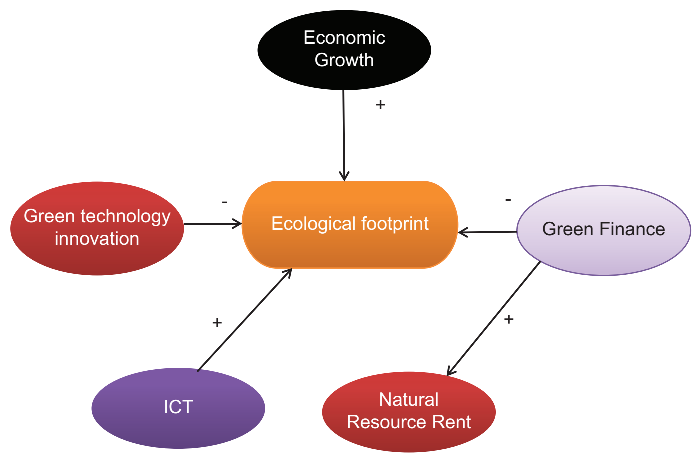
the causation series was investigated in a new way, which had been recommended by Dumitrescu and Hurlin (2012). With this procedure, the W-bar and Z-bar statistics are calculated. The results of the D-H non-causality test appear in Table 11. Ecological footprints were found to have a one-way causal relationship with information and communication technologies, green finance and economic growth. These findings suggest that green finance, information and communication technologies and the new economic growth policies in these sample economies all have a positive neutralizing effect on negative environmental impact. The D-H causality results also show no relation between ecological footprints, green technology innovation and natural resource rent.

Table 11: Answers of Dumitrescu and Hurlin panel causality test

Null hypothesis	W- bar statistics	Z-bar statistics	Probability	Decision
lnEG>>lnEFP	6.56313***	2.80892	0.0050	→
lnEFP>>lnEG	3.26911	−0.09329	0.9257	
lnGFI>>lnEFP	6.31136***	2.58710	0.0097	→
lnEFP>>lnGFI	4.03003	0.57711	0.5639	
lnGTI>>lnEFP	3.77682	0.35403	0.7233	↛
lnEFP>>lnGTI	2.42485	−0.83714	0.4025	
lnNNR>>lnEFP	4.03235	0.57917	0.5625	↛
lnEFP>>lnNNR	3.28667	−0.07782	0.9380	
lnICT>>lnEFP	16.7166***	11.6975	0.0000	→
lnEFP>>lnICT	2.39010	−0.86942	0.3846	

1% represents the level of significance. The signs>>(does not homogeneously cause), → (Unidirectional)
Source: Authors' findings with E-Views 10

Figure 2: Study's empirical findings in graphic form



5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study analyzes the interrelationship of economic growth, green technology innovation, natural resource rent, green finance, information and communication technologies and ecological footprints in the D – 8 countries. Under the framework of EKC theory, this study explores the link between economic development and ecological footprints. For this study, the data from 1995 to 2022 was used. Its initial analysis involved a co-integration analysis and unit root test, as well as a cross-section dependency test. Later, the study explored the causal chain connecting the series by means of an advanced technique proposed by Dumitrescu and Hurlin (2012). According to the results of this study, the EKC hypothesis was turned on its head in D – 8 countries. According to the research, ecological footprints increase as a result of economic growth and natural resource rent. Green technology innovation, green finance and information and communication technologies developments also reduce environmental impact. After D-H causality investigation, there is a one-sided link from the use of information and communication technologies to economic growth, green finance and ecological footprints. Causality findings further indicate that the use of natural resource rent, development of green technology innovation and ecological footprints do not interact.

5.2. Fundamental Policy Structure

The following regulatory structure is proposed for this research, based on the results of this study. The results indicate that economic growth and information and communication technologies are positively correlated with ecological footprints. Furthermore, natural resource rent, green technology innovation, and green finance exhibit an inverse correlation with ecological footprints. This discovery illustrates that the correlation between ecological footprints and all series is feeble. The research ultimately employed the variance inflation test to assess the issue of multicollinearity (Yu et al., 2021; Cai et al., 2022). One important finding of this research is that natural resource rent raises the ecological footprints in D – 8 countries. So to raise natural resource rent but not ecological impact, stakeholders and the government need to take regulatory measures. Thirdly, in combating the terrible effect green finance has on green degradation much better general understanding of this across numerous investor groups and strategy professionals is needed.

Finally, here it was suggested that the adoption of legislation to promote green technology innovation in these countries could facilitate lowering ecological footprints. Policymakers should drive investment to help the clean energy industry and take part in an energy shift; policymakers have to see more money flowing into green technology innovation. We propose that governments promote private investors to profit from green technologies, and have technical partnerships across the globe in order to ease both regional environmental concerns as well as worldwide environment. But this study also proved that better information and communication technologies help environmental sustainability. This study urges the D – 8 countries, who wish to enjoy simultaneously rising manufacturing output and fallen environmental impact of information and communication technologies, that they should continuously upgrade/redesign their national outlines for information and communication technologies. Most commonly, information and communication technologies expansion involve following methods that are healthier and more cutting edge-sustainable, renewable and environmentally friendly.

5.3. Limitations and Prospective Studies

There are many limitations in other research projects that can be considered likewise here. In this work we approve a panel of D – 8 countries, so later works may make use of the time series data to compare developing and developed countries. Corruption and responsibility are two other areas where these studies can be extended. Furthermore, a number of other elements associated with environmental pollution may be employed to see how they affect information and communication technologies and green finance. R & D, government contribution and environmental taxation are all components that can push the model further for study.

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