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Dynamics of ICT, Natural Resource, Green Innovation, and Environmental Sustainability in Developing-8 organization of Economic Cooperation Countries: A Cross-Sectional ARDL Approach

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ABSTRACT

The member states of developing-8 orD-8 organization for economic cooperation have been facing various environmental hitches posing different challenges. The interlinkages between information and communication technologies (ICT), natural resources, green finance, green innovation and environmental footprint are turning to be pivotal in this regard. This study examines the interrelationships among, natural resource rents (NRR), green technology innovation (GI), economic growth (EG), green finance (GF), and ecological footprints (EFP) in the D-8 member countries using data for the period 1995-2024. After checking data for the cross-sectional dependence (CSD), a cross-sectional augmented autoregressive distributive lag (CS-ARDL) approach is employed for the estimation. The empirical results show that natural resources increase ecological footprint. Green finance, information and communication technologies, green innovations, and technological advancements all contribute to reducing ecological footprints. The Dumitrescu and Hurlin (2012) causality testing show a one-way causal relationship between economic growth, green finance, ecological footprints, and information and communication technologies. This study incorporates new knowledge from the D-8 nations in the existing body of knowledge related to causes of environmental pollution. In addition, this study provides a benchmark by which policymakers and government institutions can evaluate their investments in the ICT, green finance, and environment-friendly technology to mitigate environmental emissions.

Keywords: Economic Growth, Green Finance, Green Innovations, Information and Communication Technology
JEL Classifications: F6, O44, Q56

1. INTRODUCTION

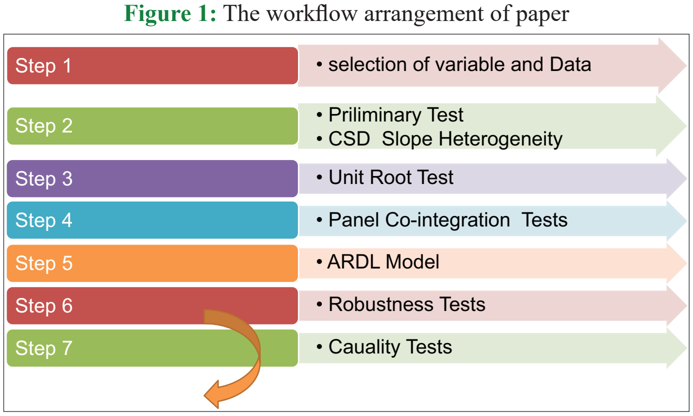
The climate change negotiations held in Glasgow at the end of year 2021 emphasized the cruciality of global climatic changes. Therefore, all countries are suggested to strengthen their mitigation plans by actively engaging in the global endeavor of reducing ecological pollution. The Glasgow Climate Agreement makes plans and rules for quickly lessening ecological footprints. The study is centered on the D-8 emerging economies including Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan, and Turkey. These are growing economies which necessitate energy consumption at a rapid pace. The Turkish economy is the highest with respect to the power consumption among the D-8 states (Akhayere et al., 2023; Mukhtarov et al., 2022). The economic activities of the developing-8 countries heavily rely on traditional fossil fuels, posing a significant risk to the organization's environmental sustainability (Canbay, 2021). Despite the D-8 nations' progress in economic growth, their environmental sustainability record is not 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 to devise a rule agenda in order to reduce the likelihood of this environmental degradation.

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 ha exists on a global scale (Sahoo and Sethi, 2021). Recently, 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. It is further asserted that green technological innovation regulates the interrelationships among environmental quality factors and that green innovation-driven commercial activities contribute to the environmental quality (Zhang and Li, 2020). 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; Sahoo et al., 2024). Particularly, in developing countries, access to costly environmental technologies is unattainable due to financial constraints. High-income developing countries and emerging economies can afford to procure the necessary funds for environmental technology. On the other hand, poorly growing countries still have to keep a production system based on fossil fuels. In the 1990s, the connection between economic growth and natural resources was focused by the experts. The environmental kuznets curve (EKC) is the concept which suggests an inverted U-shaped relation between GDP and environmental emissions. 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, and fossils to satisfy the demand.

Fossil fuel, one of the traditional energy sources, is impacting ecological footprints (Li et al., 2023; Li et al., 2022; Qing et al., 2024). More research is being done on the interaction between ecological footprints and green finance, which has turned into an original battleground among environmental experts. It is imperative to annotate that green finance is an investment plan that objects to supporting environmental maintenance. Therefore, green finance provides a platform for private investors to pick up the slack that is inadequately filled by public expenditures (Muganyi et al., 2021). In most countries, the ecological footprint is in deficit if natural resource rent is used up rashly. According to Khan and Ulucak (2020), large-scale economic expansion leads to greater exploitation of natural resource rent, undermining environmental sustainability in the process. The ICT relationship with economic growth is another concept related to environmental sustainability. Now a days, ICT has become an important factor in promoting human welfare and economic growth. According to some studies, the rise of ICT is negatively correlated with environmental contamination helping to improve quality of life (Caglar et al., 2021; Jie et al., 2023). Therefore, evaluating the effects of ICT 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 explores how economic growth, natural resource rent, ICT, and green technology innovations interact over time.

Figure 1: The workflow arrangement of paper



This study is a useful contribution to environmental research because (1) ecological footprints are often used as the standard for measuring all different kinds of environmental emissions. The existing literature has criticized the use of ecological footprints alone to define environmental emissions because ecological footprints only include a small proportion of multifaceted environmental emissions (Majeed et al., 2021; Dogan et al., 2022; Addai et al., 2022). (2) This is an initial attempt to examine the issue by incorporating green finance, natural resource rents, green technology innovations and ICT. As a result, this study provides a profound examination about the way in which these variables are related to environmental emissions in case of the D-8 nations. The study uses the second-generation tests to check the cross-sectional dependence. To determine whether or not the long-term interactions exist among the series, three different methods are employed considering Pedroni and Kao (1999). The present study uses the ARDL approach developed by Chudik and Pesaran (2015) for the short-run as well as the long-run estimation. This research utilizes contemporary techniques such as Pesaran (2007) common correlated effects means group estimator and the augmented mean group method to have robustness checks. Finally, the Dumitrescu and Hurlin (2012) test has been used to test for any potential causality between the variables under consideration.

2. LITERATURE REVIEW

This section investigates the relationships between ecological footprints, information and communication technologies, natural resource rents, green technology innovations, green finance, and ICT.

Many seminal works reflect the beneficial impact of green finance in reducing resource depletion. The environmental Kuznets curve proposition validates the significance of green finance in maintaining ecological sustainability (Tariq and Hassan, 2023). Focusing the environment-friendly policies and practices is essential in this era of growing environmental issues. Nawaz et al. (2021) point out that green finance is an overarching term that focuses on financial investment in support of sustainability efforts and environment-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 Karim (2022) evaluated how green finance influenced environmental preservation in the top ten green finance-investing economies.

Over the past 30 years, the ICT industry has seen intense competition as Businesses, governments, and consumers have all increased their use. Fryer (2019) identifies two potential applications of ICT in mitigating environmental pollution. Firstly, information and communication technologies can do this by using renewables and efficient energy usage. Secondly, ICT can reduce transportation emissions due to remote work. According to research, the low energy consumption accompanying information and communication technologies lowers ecological footprint levels. Environmental pollution is the task of today's world to create a healthier planet with technology. Enhanced technologies provide an additional glimmer of optimism regarding the attainment of sustainability (Ahmed et al., 2017). The data indicates that financial expansion and ecological footprint has a tradeoff relationship. Aydin and Turan (2020) discovered a similar point of view when they examined the ecological footprint through EKC theory, incorporating trade policies, financial openness, and economic stability. Our recent research on green credit, securities, insurance, and investments has conclusively proven that these environment friendly steps significantly decrease harmful atmospheric emissions. As long as we can adopt these measures, human lifestyles will bring a positive change in the ecology. There are currently 4.67 billion active internet users worldwide, and information and communication technologies offer quick solutions for all types of enterprises through massive communication infrastructures. Internet use and cellular subscriptions on mobile devices may be used as proxies for information and communication technologies (Khan et al., 2022).

It is lately investigated that there is a connection 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 association between natural resource rent and ecological footprints among emerging nations. The findings suggest that a higher use of natural resource results in environmental deterioration. However, the negative ecological footprints of natural resource rents can be mitigated by implementing current technological innovations in natural resource usage. Erdoğan et al. (2021) stated that sub-Saharan African economies overly rely on natural resource rents for economic progress has led to increased environmental pollution. According to Ibrahim and Ajide (2021), ecological footprint in the BRICS countries was influenced by natural resource rents, financial development, and regulatory quality. Furthermore, Kongbuamai et al. (2020) suggested that the effective use of natural resource rents might be central to environmental sustainability.

It is projected that the green technology innovations would significantly reduce environmental pollution. The host countries' environmental sustainability has risen due to technological innovations and environmental regulations. Several researchers have examined the nexus between environmental quality and green technology innovations. The researchers discovered that technological progress is essential in reducing carbon emissions. Some scholars have discussed whether technological innovations benefit or damage the environment. Technological innovation play a significant role in improving the environmental quality (Adebayo and Kirikkaleli, 2021). Balsalobre-Lorente et al. (2018) inspect the correlations between green energy, technical innovations, and environmental quality in the European countries using a dataset for the period 1985-2016. The researchers suggest suitable measures to mitigate CO_2 emissions and foster sustainable development. They found that trade lowers environmental quality, whereas renewable energy and technical progress improve it.

Grossman and Krueger (1995) examined the EKC hypothesis in the light of trade agreements and environmental emissions in North America. The results are diverse about the Environmental Kuznets Curve theory. Uddin et al. (2017) used panel data set for the period 1991-2012 to examine the relation between economic development and ecological footprint among 27 high CO_2 emission states. Their findings suggested that an expanding economy has larger ecological footprints. Similarly, Ahmed et al. (2019) used panel data for the period 1971-2014 to examine the relationship between economic growth and ecological footprints in Malaysia. According to their empirical research, economic growth raises the ecological footprints. According to research by Mrabet and Alsamara (2017) on economic growth 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 degradation may occur due to high economic growth. Naqvi (2021) uses a large panel of 155 countries to show that financial development reduces CO2 emissions. Wang et al. (2025) relationship between economic efficiency, renewable energy, financial development, industrialization, and environmental footprint in the 36 OECD states. It is found that renewable energy and financial sector developmentmake positive effect of economic efficiency on the environmental footprint weak, while industrialization strengthens it.

3. EMPIRICAL METHODOLOGY

3.1. Overview of Variables and Data Sources

A panel data set for the period 1995-2024 has been collected on developing-8 (D-8) member countries namely Bangladesh, Indonesia, Iran, Malaysia, Türkiye, Egypt, Pakistan, and Nigeria.

The data on ecological footprints was found from the Global Footprint Network. The WDI database is the source for green finance, information and communication technologies, Economic growth, and natural resource rent indicators. The OECD database was used to get green technology innovations data. The details on measurement, symbols, and sources of data for each variable are shown in the Table 1.

3.2. Model Specification

The econometric technique used in this study is mathematically stated as Eq. (1) which is developed on the basis of EKC model specification by Haldar and Sethi (2022). We depict the relationship in the econometrics specification as given below,

$$lnEFP_{it} = \gamma_0+\gamma_1 lnGDP_{it}+\gamma_2 lnGF_{it}+\gamma_3 lnGI_{it}+\gamma_4 lnICT_{it}+\gamma_5 lnNRR_{it}+\epsilon_{it} \quad (1)$$

In the equation, the ecological footprint is a dependent variable while economic growth or gross domestic product (GDP), Green finance (GF), green innovations (GI), information, communication, and technology (ICT), and natural resource rents (NRR) appear as independent variables.

We use the natural logarithm of each series for narrow down the high magnitudes. This also helps improving the heteroskedasticity and autocorrelation problems in the series. The notation ln denotes the series natural logarithm, ∈ is the error terms. Also, the notation 'i' represents the cross sections and 't' shows the time period.

3.3. Summary Statistics and Correlations

Table 2 presents descriptive statistics for all the series. The findings also indicate that the selected series have a relatively high standard deviation. There is likelihood that the variables under consideration will exhibit heterogeneity. The results of the bivariate correlation study are shown in Table 3. The empirical results designate 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. We employed the variance inflation factor test to assess the issue of multicollinearity. As shown in Table 4, the findings demonstrate the absence of multicollinearity because both the mean and VIF values are <10.

3.4. Empirical Methodology

After the selection of variables and collecting data, cross-sectional dependence and slope homogeniety tests are performed. The second generation panel unit root tests are performed on panel data befor apllying panel cointegration testing. The panel ARDL approach is the next step which gives us long-run coeficients and short-run behavior of variables. The robustness checks and Demitris-Hurlin causality tests are performed at the last stage. The workflow details are provided in the Figure 1.

3.4.1. Cross-sectional dependence (CD) test

The CD test checks any interdependence between the panels of countries. This test also provides a clue about the suitable estimation methods used to apply cointegration testing. This test follows the mathematical formula as given below:

Table 1: Description of data

Indicators	Symbol	Nature	Measurement	Source
Ecological footprint	EFP	Dependent	Global Hectare per capita, EFP (gha)	GFN
Green finance	GF	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 US dollars)	WDI
Natural resource rent	NRR	Independent	Natural resource rent % GDP	WDI
Green technology innovations	GI	Independent	Green patents	OECD

Table 2: Summary statistics

Measures	EFP	GDP	GF	GI	ICT	NRR
Mean	−0.053547	7.704370	2.677741	2.178666	1.833300	1.413197
Median	−0.076551	7.704370	2.677741	2.178666	2.514277	1.630588
Maximum	1.618655	9.434108	4.485034	3.698830	4.581902	3.549016
Minimum	−2.474157	5.774822	−0.820981	0.029559	−9.003326	−1.938484
Standard deviation	1.012106	0.951496	1.373079	0.558328	2.538182	1.322921
Sum	−12.85118	1849.049	642.6578	522.8798	439.9919	339.1673
Observations	240	240	240	240	240	240

All variables are in log form

Table 3: Correlation matrix

Variable	EFP	GDP	GF	GI	ICT	NRR
EFP	1.000000					
GDP	0.348909	1.000000				
GF	0.284553	−0.553787	1.000000			
GI	−0.211185	0.060852	−0.043764	1.000000		
ICT	0.189649	0.676881	−0.269369	0.027425	1.000000	
NRR	−0.349354	0.026884	−0.413842	0.124038	0.030650	1.000000

All variables are in log form

Table 4: Variance inflation factor analysis (VIF)

Variable	VIF	I/VIF
LNGDP	2.77	0.3609
LNGF	1.96	0.5097
LNGI	1.02	0.9774
LNICT	1.93	0.5182
LNNRR	1.34	0.7454
Mean VIF	1.18	-

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

Equation (2) shows the time, the cross-sectional dependence in the panel (represented by N), and the correlation coefficient between i and m units (represented by ∂_{im}).

3.4.2 Slope homogeneity test

The test to check the slope homogeneity test in panel data was first suggested by Pesaran and Yamagata (2008). Mathematically, It can be written as follows:

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-}\tilde{S} - K}{\sqrt{2K}}\right) \quad (3)$$

$$\tilde{\Delta}adj = \sqrt{N}\left(\frac{N^{-}\tilde{S} - E\left(\tilde{Z}\,it\right)}{\sqrt{var\left(\tilde{Z}\,it\right)}}\right) \quad (4)$$

3.4.3. Unit root tests

The second-generation unit root testing is vital in the presence of cross-sectional dependence. The Cross-sectionally augmented Im, Pesaran and Shin (CIPS) test and cross-sectionally augmented Dickey-Fuller (CADF) unit root tests are applied in this regard. These tests provide the order of integration of the variables of our model.

3.4.4. Panel cointegration testing

The co-integration approach developed by (Pedroni, 2004) explores the long-run 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 empirically presented in Equation (5) as mentioned by (Pedroni, 2004):

$$\hat{\varepsilon}_{it} = \rho_i \hat{\varepsilon}_{it-1} + \sum_{j=1}^{k}\varphi_{ik}\Delta\hat{\varepsilon}_{it-k} + v_{it} \quad (5)$$

The cross sectional dependence and heterogeneity in the research series were also analyzed using (Westerlund, 2007) the co-integration technique. There is no co-integration exists among the series. The mathematical expressions for this test are:

$$G_t = \frac{1}{N}\sum_{i=1}^{N}\frac{n_i}{S.E\left(\widehat{n_i}\right)} \quad (6)$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{Tn_i}{1-\sum_{j=1}^{k}\widehat{n_{ij}}} \quad (7)$$

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

$$P_t = \frac{n_i}{S.E\left(\widehat{n_i}\right)} \quad (8)$$

$$P_a = Tn_i \quad (9)$$

3.4.5. Longrun estimation models

Our study uses Chudik and Pesaran (2015) CS-ARDL to evaluate the short- and long-term estimates. EFP is environmental foot print and Z is the vector of control variables. The estimates are more reliable which can be represented mathematically as:

$$\Delta EFP_{i,t} = \varnothing_i + \sum_{I=0}^{p\omega}\varnothing_{ij}\Delta EFP_{i,t-1} + \sum_{I=0}^{pz}\varnothing_{ij}\Delta AEV_{i,t-1} + \sum_{I=0}^{pz}\varnothing_{ij}\Delta Z_{i,t-1} + \epsilon_{i,t} \quad (10)$$

3.4.6. Robustness checks

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

3.4.7. Causality analysis

We employed Granger causality test developed by Dumitrescu and Hurlin (2012) to look at the dynamic relationships between series. This strategy supports in addressing the potential cross section dependence and slope heterogeneity issue. The null hypothesis of Dumitrescu and Hurlin (D-H) Granger causality test is that there is no causal link between the variables. The model's causal relation, on the other hand, is the alternative theory. The mathematical expression for the D-H non-causality test is given in equation 11:

$$Y_{it} = \alpha_i + \sum_{M-1}^{M}\gamma_i^{m}\,, Y_{I(m-t)} + \sum_{M-1}^{M}\delta_i^{m}\,, Z_{I(m-t)} \quad (11)$$

4. RESULTS AND DISCUSSION

4.1. Cross-Sectional Dependence and Slope Homogeneity Testing Results

To observe the cross-sectional dependence among the series, two tests were used. The Table 5 gives the results of the cross - sectional dependence testing. The results confirm the rejection of the null hypothesis of dependence among the cross sections at 1% level of significance. As a consequence of this, these results designate that the D-8 countries are interrelated in economic growth, information and communication technologies, natural resource rent, green finance and green innovation technology. Table 6 presents the results 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 of cross - sectional dependence and heterogeneity are presented in the next section.

4.2. Unit Roots Test

Testing the stationarity level and determining the order of integration of series is vital. Analyzing the stationarity of the variables is critical when investigating panel data. Existing literature shows that non-stationarity of a series 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 most popular second-generation unit root tests to look at the stationarity of the series. Table 7 demonstrates that GI, ICT are level stationary, but all the other series are first order stationary 1(1).

Table 5: Summary of the CSD findings

Series	Breusch–Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM
lnEFP	341.6246***	41.90985***	41.77192***
lnGDP	471.1403***	59.21712***	59.07919***
lnGF	435.6003***	54.46788***	54.32995***
lnGI	73.14600***	6.032888***	5.894957***
lnICT	586.4575***	74.62703***	74.48909***
lnNRR	291.6626***	35.23340***	35.09547***

Table 6: Summary of the slope homogeneity test

Measures	Value	P-value
Delta	3.231***	0.000
Adj	3.893***	0.000

Table 7: Summary of unit root test

Variable	CADF test		CIPS test	
	1 (0)	1 (1)	1 (0)	1 (1)
LnEFP	14.0077	28.7337**	0.9521	−6.5652***
LnGDP	7.2318	46.6620***	1.456	−4.1810***
LnGF	3.5322	83.4723***	4.1095	−7.41972***
LnGI	54.8133***		−4.93814***	
LnICT	64.1904***		−5.25433***	
LnNRR	8.9021	107.594***	0.90500	−9.34277***

***: 1%, **: 5% and *: 10% significance level

4.3. Panel Co-integration Test

In this study, we proved that the long-term relationship among these series existed by using three methods. The findings of the Pedroni (2004) co-integration test are in Table 8. According to the Pedroni co-integration test, 7 out of 11 statistics reject the null hypothesis of no co-integration.

The long run relationship is rechecked by the Kao (1999) and Westerlund (2007) co-integration tests. The Kao test statistic indicates the rejection of null hypothesis. The Westerlund co-integration test shows that two statistics reject the null hypothesis of no co-integration. The findings of Kao (1999) about co-integration also show a long term connection between the chosen series.

4.4. Long-run and Short-run Results of CS-ARDL

The short-run and long-run coefficients by employing CS-ARDL technique are presented in the Table 9. In the long-run 1% increase in GDP will increase in ecological footprint by 0.044% or vice a versa. The rise in GDP leads to more industrialization for production leading to higher ecological foot print. The coefficients on green finance is positive and statistically significant. The long-run coefficients of green finance has very low value of 0.001%. The coefficient on green innovations, and natural resource rents are negative and statistically significant. It means that green innovations and natural resource rents help in reducing environmental footprint. By green innovations, green production is triggered by companies are by using less-polluting technology in their production processes. The

Table 8: Summary of co-integration test

(Pedroni, 1999; 2004)					
Within dimensions	**Statistic**	**Prob.**	**Between dimensions**	**Statistic**	**Prob.**
Panel v-statistic	2.4097***	0.008	Group rho-statistic	−2.7823	0.99
Panel rho-statistic	0.5284	0.70	Group PP-statistic	−0.0451	0.48
Panel PP-statistic	−1.9371**	0.02	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		Gt	−1.701***	0.000
	−1.2224***	0.00	Ga	1.713	0.94
			Pt	−2.131***	0.002
			Pa	2.44	0.94

beneficial effects of natural resource rents on environmental quality are indicated by coefficient values of −0.1254. It means that the usage of natural resource rent would promote economic development with reduced resource use and depletion. Hence, the presence of natural resource rent means that there's less money for companies to use. This causes the lower ecological footprints.

The coefficient on ICT is negative and statistically significant. The interpretation of this finding can be supported by the supposition that ICT improve energy efficiency and savings via decreasing environmental pollution. Additionally, ICT promotes businesses to incorporate cutting-edge technology into their operations which lowers emissions. The long-term results align with the short-term findings. Also, our findings are in line with Salahuddin et al., 2016; Mehmood et al., 2022; Wang et al., 2023.

Table 9: Summary of CS-ARDL results

Variable	Coefficient	Standard error	P-value
Long run analysis			
lnGDP	0.0443***	0.0110	0.0000
lnGF	0.1100***	0.0656	0.0000
lnGI	−0.044317***	0.011037	0.0001
lnICT	−0.0225**	0.0100	0.0091
lnNRR	−0.1254**	0.0567	0.0300
Short run analysis			
COINTEQ01	−0.5763**	0.3002	0.0546
lnGDP	0.4035***	0.0586	0.0000
lnGF	0.1651***	0.0464	0.0005
lnGI	−0.0180	0.0300	0.5480
lnICT	−0.0209**	0.0101	0.0390
lnNRR	−0.02096***	0.0037	0.0001

Dependent variable: LNEFP. *** = 1%, ** = 5% and * = 10% significance level.

Table 10: Robustness check

Variables	FMOLS	DOLS
LnGDP	0.2631***	0.148523***
LnGF	0.1285***	0.018211*
LnGI	−0.1472***	−0.0566**
LnICT	−0.0371**	−0.0336***
LnNRR	−0.0151*	−0.0170*

***: 1%, **: 5% and *: 10% significance level

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 presented in Table 10. This indicates that our conclusions are reliable and applicable to the D-8 countries. The empirical results from this investigation are presented graphically in Figure 2.

4.6. Dumitrescu and Hurlin (D-H) Causality Test

The CS-ADRL method only gives short term and long-run estimates. So, these methods need to prove that there is a cause-and-effect relationship present. The W-bar and Z-bar statistics are calculated. The D-H causality test results are presented in Table 11. Ecological footprints were found to have a one-way causal relationship with ICT, green finance and economic growth. These findings suggest that green finance, information and communication technologies and economic growth in the sample economies all have a positive neutralizing effect on negative environmental impacts. The D-H causality results also show no relation between ecological footprints, green technology innovation and natural resource rents.

Figure 2: The study's empirical findings in graphical form

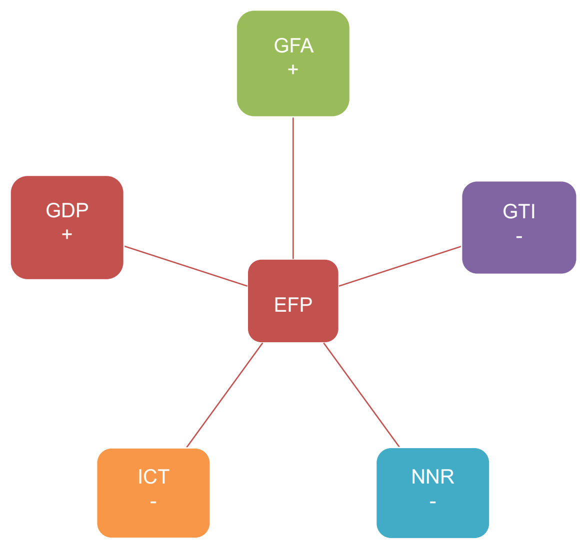


Table 11: Dumitrescu and Hurlin panel causality test

Null hypothesis	W-stat	Z-bar-Stat	Probability	Decision
lnGDP>>lnEFP	1.4838	−0.8292	0.4070	↛
lnEFP>>lnGDP	2.8096	0.7266	0.4675	
lnGF>>lnEFP	19.3565***	20.1460	0.0000	→
lnEFP>>lnGF	3.46766	1.49890	0.1339	
lnGI>>lnEFP	1.43496	−0.88667	0.3753	↛
lnEFP>>lnGI	1.30410	−1.04025	0.4025	
lnNRR>>lnEFP	15.9667***	16.1677	0.0000	→
lnEFP>>lnNRR	2.6470	0.5358	0.5921	
lnICT>>lnEFP	0.9446	−1.4620	0.1437	→
lnEFP>>lnICT	70.2942***	79.9265	0.0000	

5. CONCLUSION AND POLICY IMPLICATIONS

This study is an attempt to uncover the relationship between economic growth, natural resource rents, green finance, green innovations, ICT and ecological footprint in the D-8 economies. A panel data set for the period 1995-2024 has been used for the estimation. After evaluating the cross-sectional dependence, CS-ARDL approach is employed to obtain short-run and long-run results. Initially, unit root tests are performed along with cross-sectional dependence testing. The empirical results designate that GDP growth and the ICT are positively correlated with ecological footprint. The natural resource rent, green technology innovation, and green finance exhibit an inverse association with the ecological footprint. The empirical findings illustrate that the correlation between ecological footprint and all other series is feeble.

The Dumitrescu and Hurlin causality test is also employed to check the cause and effect relationship between the variables. According to the results, green technology innovation, green finance and information and communication technologies reduce environmental footprint. It is also noticed that there is a one-way causality between information and communication technologies to economic growth and green finance to ecological footprint. Causality test findings further indicate that the use of natural resource rent, development of green technology innovation and ecological footprints have no clear cause and effect relationship.

The policies should focus on the adoption and promotion of green technology innovation to lower the ecological footprint. The policy measures should be taken to attract investments in the clean energy projects green technology innovation. The governments should promote private investments in this regard. The better information and communication technologies (ICT) infrastructure should be boosted to help the environmental sustainability.

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