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Exploring the Role of Communication Technologies, Governance, and Renewable Energy for Ecological Footprints in G11 Countries: Implications for Sustainable Development

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Abstract: Today, the world is confronted with the issue of environmental pollution as a result of our dependence on fossil fuels for our energy needs. Developed and developing countries are therefore adopting different strategies to curb environmental problems. This work is thus designed to probe the effect of renewable energy (RE), information and communication technologies (ICT), government stability, and GDP on ecological footprints (EF) in G11 nations. We utilized the annual data from 1990–2020 and applied robust methodologies to present the findings. The CS-ARDL method shows that renewable energy, ICT, and government stability are essential factors in lowering environmental pollution in G11 countries. Therefore, in light of the findings, this work suggests an increase in the use of RE sources such as solar, wind, and hydropower in the total energy mix of the various countries. RE usage improves air quality and saves the natural environment from further destruction. The countries also need to enhance their communication technologies in the economic sector. Moreover, policymakers must also introduce the required policies that would promote the use of RE in various countries. This will make people adopt clean energy sources at the domestic and commercial levels.

Keywords: ecological footprints; government stability; renewable energy; G11 countries; CS-ARDL

1. Introduction

The problem of environmental degradation is continuously becoming severe across the world. Rising temperatures, melting glaciers, and floods continue to negatively affect lives and properties and, as a result, require immediate action. The international agreement of Paris resolves to keep the rising temperature below 2 degrees Celsius [1]. By investigating the environmental Kuznets curve (EKC), various studies have shown that fossil fuels hold the leading role in contaminating the environment [2]. From 1997 to 2011, ~78% of total greenhouse gas emissions were caused by the combustion of fossil fuels [3]. Huge population and rapid economic growth have increased the energy consumption of these countries. As a result, these countries have tried to lower energy costs and restructure their energy systems. In this regard, alternative sources of energy are being introduced to mitigate environmental pollution globally [4]. The economies that have introduced renewable energy (RE) in their total energy mix are on the right track to growing sustainably. Other countries that are still consuming nonrenewable energy sources are lagging behind in terms of environmental cleanliness [5]. In this regard, clean energy resources are helping developing countries to grow their economies with lower environmental pollution. Efficient energy policies and technological transformation can curb environmental degradation [4].

The group of eleven (G11) countries, as shown in Figure 1, have also shown their commitment to using RE sources. According to the World Bank database (Figure 1), RE consumption has not been steady since 1990, but after 2015, these countries have consistently increased their consumption of RE. This shows their commitment to a cleaner environment. Considering the negative impact of environmental pollution, these countries are required to increase their clean energy usage in their total energy mix [6].

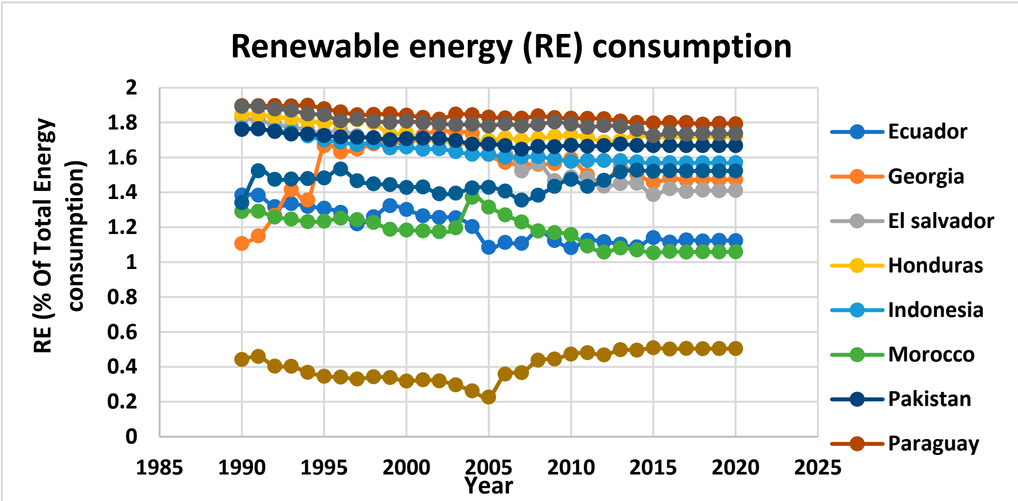

Figure 1. RE consumption in G11 countries.

The current study aims to investigate the following questions in G11 countries:

1. What is the role of change in RE consumption in curbing ecological footprints (EF);
2. Given the political instability in these countries, what is the role of governance towards EF;
3. What are the econometric results of other factors towards EF?

Hence, this study seeks to probe the associations between RE, information and communication technologies (ICT), governance, and GDP in G11 nations. For empirical analysis, we incorporated the annual data from 1990 to 2020 and applied the cross-sectional autoregressive distributed lag (CS-ARDL) approach. CS-ARDL is useful for providing long-run and short-run results. This method also controls the cross-sectional dependence (CD) in the data. The findings were also cross-checked by other robust methods such as dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and CCR tests. Therefore, this work enhances the current wave of knowledge by investigating the socio-economic factors of EF. CO_2 is considered an environmental pollution proxy in various studies. However, CO_2 emissions alone do not provide a complete picture of environmental pollution. Therefore, the current study presents a comprehensive measure of environmental pollution. EF includes different parameters, such as fishing grounds, cropland, and other industrial areas.

Figure 2 shows the variation of EF in G11 countries. It can be observed that all countries are striving to control environmental pollution, but EF is increasing gradually, except in Paraguay. This means that these countries are still consuming fossil fuels to keep up their GDP.

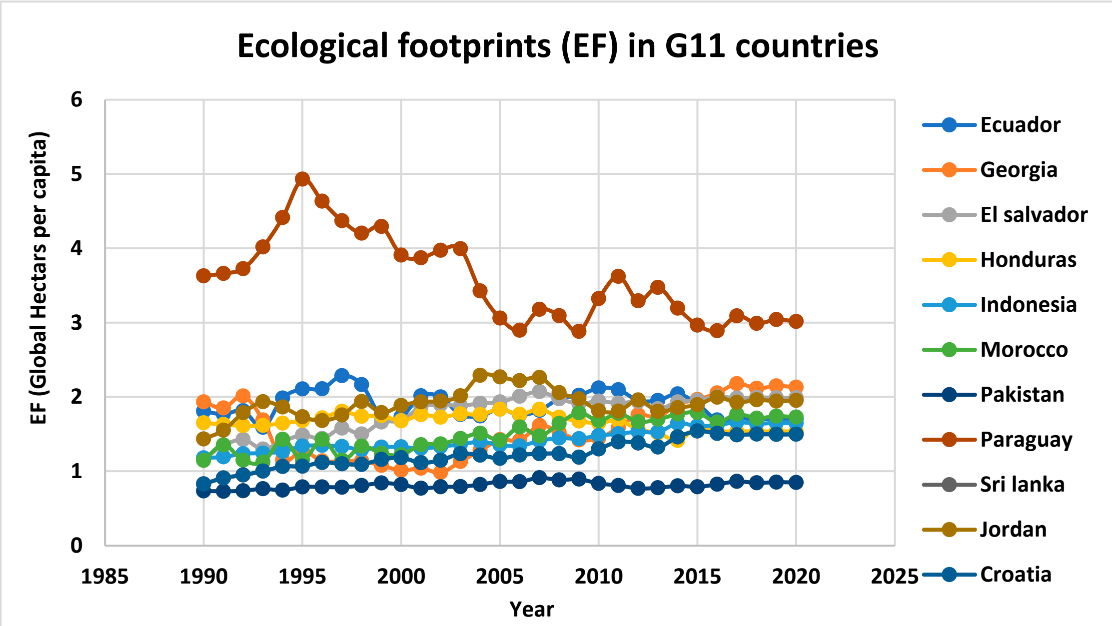

Figure 2. EF in G11 nations; source Global Footprint network.

Contribution of This Work

This work contributes to the literature in the following aspects: firstly, it includes factors of governance such as ICT, GDP, and EF in G11 nations (Pakistan, Croatia, Honduras, Jordan, Indonesia, Georgia, El Salvador, Ecuador, Sri Lanka, Paraguay, and Morocco. Most of these are developing nations that are mutually working to reduce their debt burden and also increase their GDP by incorporating natural resources. Secondly, this work applies the second-generation robust econometric techniques to the annual data from 1990 to 2020. Thirdly, with the use of the CS-ARDL technique, probing the role of ICT and governance in the EF of G11 countries is the novelty of the study. This analysis will help us understand the factors that affect EF in the G11 economies, and it may also help in policy application to lessen the ecological discrepancy of the countries and improve the quality of life.

The rest of the manuscript is organized as follows: the literature review is in Section 2. Data description and the methodology are presented in the Section 3. The fourth part consists of the results and discussion. Section 5 is about conclusions and the policy implications.

2. Literature Review

In this section, the related literature is provided to develop a hypothesis. Because of global warming, studies relating to climate have gained momentum over the last decade [7]. Nowadays, the ecological footprint has been used as a new parameter for the interpretation of ecological deprivation [8–12] because it gives a better understanding than CO_2 emissions. In order to measure the degree of sustainability for development, an ecological footprint analysis is a more suitable method for the ecological economy [13]. Upon further investigations, it is noted that EF has a long-lasting effect on high- and low-middle-income economies [14]. Different studies observed the theoretical and empirical basis of the linkages of RE, finance, urbanization, and GDP [15–19]. The current research broadened the scope by including factors of a government's effectiveness, as well as information and communication technologies. The factor of governance was introduced because it has an impact on a country's GDP. Governance does not consist of the government only. It also consists of institutions and business entities. According to [20], governance has six dimensions, i.e., accountability, regulatory quality, government effectiveness, political stability, the rule of law, and control of corruption. The list of abbreviations is presented in Table 1.

Table 1. List of Abbreviations.

Abbreviations	
EF	Ecological footprints
CO_2	Carbon dioxide
ICT	Communication technologies
GDP	Gross Domestic Product
RE	Renewable Energy
GOV	Governance
DOLS	Dynamic ordinary least squares
CS-ARDL	Cross-sectional autoregressive distributed lag
FMOL	Fully modified ordinary least squares
EKC	Environmental Kuznets curve
GOV	government effectiveness
WDI	World Bank Indicator
CD	Cross-sectional dependence
ICRG	international country risk guide
CIPS	Cross-sectionally augmented Im-Pesaran-Shin

2.1. Renewable Energy and Ecological Footprints

According to [21–23], RE curbs environmental pollution. Several research studies agree that RE mitigates environmental pollution [24,25]. The work of [12,26] has documented that RE usage significantly lowered CO_2 emissions in Pakistan from 1970 to 2012. A recent study by [27] of data from 1998 to 2018 applied the ARDL method for Chinese data and found that RE mitigates CO_2 emissions. However, [28] showed that RE did not mitigate environmental pollution in Thailand, Turkey, and Pakistan by studying data from 1990 to 2016. The work of [29] confirmed that RE increases the production of CO_2 in the long run; however, it does not affect it in the short run. Similarly, [30] found that RE enhances environmental pollution but is not harmful in the short run for BRICS economies.

Hypothesis 1. *Forms of RE can reduce environmental destruction through the reduction in EF.*

2.2. Government Effectiveness and Ecological Footprints

The study of [31] provided theoretical evidence that political stability and control of corruption reduce environmental pollution. Moreover, a measure such as democracy has been identified as having a positive impact on environmental quality. These findings, however, changed when the control of corruption and democracy was assessed to evaluate their impact on environmental quality [32,33]. Democratic and social factors jointly impact environmental quality due to social justice and environmental awareness [34]. Additionally, RE projects can provide collaborative structures that can ultimately improve environmental governance [35]. Recently, a study by [36] of data from 1990–2020 proposed that political stability can improve environmental quality. Governance can mitigate CO_2 emissions in South Asian countries [37]. The same findings were revealed in BRICS by [38]. Similarly, a study by [39] of data from 1996 to 2020 indicated that governance is environmentally sustainable for the MENA region.

Hypothesis 2. *Government stability can contribute to environmental quality in G11 countries.*

2.3. GDP and Ecological Footprints

The major contributors to environmental pollution are urbanization, energy use, and GDP, both in developing and developed countries [40]. Other contributors include construction sites, food waste, and the transport sectors. According to [41], there is a simultaneous relationship between income and CO_2 pollution in Asian nations using data from 1965 to 2010. The study by [42] examined a one-directional causality among GDP and CO_2 emissions in developing nations from 1965 to 2006. Their study proposed a switch from traditional energy sources to clean energy for the study areas. Ghosh [43] analyzed data from 1971 to 2006 in India and found two-way causality between environmental degradation and GDP. The study identified that the mitigation of CO_2 emissions could affect the GDP of India. Similarly, [44] found how EF is linked with economic progression and suggested that economic progression increases EF. At the same time, several studies [45–49] probed the linkages between energy use and GDP. Oh and Lee [47] probed the role of energy use on employment and GDP during 1970–1999, while [49] also investigated the same nexus for Canada.

Hypothesis 3. *GDP positively affects environmental quality.*

2.4. ICT and Ecological Footprints

The implementation of policies is strongly linked with governance. Therefore, governments must be careful in adopting efficient tools for effective policy execution. Today, digital technology has become an essential tool in our lives. Therefore, it can be an important tool for government transparency and structural change. In this context, it is essential to evaluate the effect of ICT on environmental quality. This linkage was explored firstly in developed countries because of the emergence of new technologies. Research studies indicated that 2% of all human-created CO_2 emissions are from ICT, generated from transport activities, economic drivers, and energy sources. The ICT sector includes any intermediate inputs that create CO_2 emissions. Therefore, ICT-related services and goods can be considered polluting factors.

Apart from the above discussion, advanced technologies are considered an important factor in mitigating environmental pollution. Research studies have shown the importance of clean energy in the ICT sector [50]. ICT provides rapid solutions for all kinds of businesses through vast communication systems. Today, are about 4.67 billion global active internet users [51]. Internet usage and mobile cellular subscription have been taken as a proxy for ICT [52]. The studies of [53,54] have indicated that the main measure of ICT is the internet which consumes electricity that could increase environmental pollution. On the other hand, some researchers claim that internet use has no impact on CO_2 emissions and enhances energy efficiency [54–56].

2.5. The Gap in the Literature

Although the above-reviewed literature has presented several works that investigated the linkages of RE, governance, ICT, and GDP, there is a gap in the literature that needs to be filled. Numerous studies investigated the impact of RE on CO_2 emissions, but very few of them studied the impacts of RE on EF. Moreover, very few studies considered the role of ICT on EF. To the best of our knowledge, ours is among the few studies that probed the impact of government's effectiveness, ICT, RE, and GDP on the EF of G11 countries from 1990–2020. This study is an attempt to know the impact of governance EF in G11 nations.

3. Data Description and Methodology

A set of methods are applied over the panel data of the 1990–2020 period for RE, EF, ICT, and government effectiveness (GOV) in G11 countries. Tables 2 and 3 show the data sources and the descriptive statistics, respectively.

Table 2. Data sources.

Parameters	Symbol	Unit	Source
Ecological footprints	EF	Global Hectars per capita	GFN
Communication technologies	ICT	Individuals using the internet (% of total population)	WDI
Gross Domestic Product	GDP	constant US dollars	WDI
Renewable Energy	RE	% Of Total Energy consumption	WDI
Governance	GOV	Government stability	ICRG

Table 3. Descriptive statistics.

	Median	Mean	Minimum	Maximum	Std. Dev.
EF	1.59	1.69	0.73	4.93	0.72
GDP	2979.01	3642.21	736.95	16,509.91	3084.79
GE	7.75	11.34	1.83	76.00	13.20
ICT	6.11	16.56	0.00	79.08	21.30
RE	39.94	38.43	1.69	79.15	21.17

EF comprises the productive areas for a specific area or people. It considers the ecological possessions we need to generate the natural resources we consume. It is measured in global hectares. The footprint of a country or an individual comprises the sea or land of the whole world because trade is global. Communication technologies include the persons utilizing the internet, a percent of the total population. The data for ICT for some countries started in 1995. Therefore, some values are added by the method of interpolation to make a balanced panel. Gross domestic product is in USD in constant terms. RE is the percent of total hydro, wind, and solar energy. The international country risk guide provided governance data. The data consist of 22 factors in three subcategories of financial, political, and economic risk. The political risk index has 100 points. More points in a country show political stability, and lower points show more political risk. This work took the log form of all the data for consistent results. The mathematical expression equation for the model is:

$$lnEF_t = F(RE_{it}, ICT_{it}, G_{it}, GOV_{it}) \quad (1)$$

$$lnEF_t = \beta_0 + \beta_1 \, lnRE_{it} + \beta_2 \, lnICT_{it} + \beta_3 \, lnG_{it} + \beta_4 \, lnGOV_{it} + \epsilon_{it} \quad (2)$$

where, i, t, ϵ_{it} and β represent years, cross sections, error term, and coefficient values, respectively. EF, RE, ICT, G, and GOV, represent ecological footprint, renewable energy, information and communication technologies, GDP, and government stability, respectively.

3.1. Methodology

The method employed for the analysis is discussed in this section.

3.1.1. Cross-Sectional Dependence (CD) Test

The methodology starts with the introduction of the CD test. It reveals any dependence among the countries. The test results also give an indication of the econometric techniques that will be utilized for the cointegration and long-run coefficient values. This work continues with the application of CD by [57]. The mathematical expression is:

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

Equation (3) presents cross section, time, and error association in terms of N and T and ∂_{ij}^{t}, respectively.

3.1.2. Slope Homogeneity Test

Pesaran and Yamagata [58] introduced the panel data nature. Mathematically it can be expressed as:

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

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

3.1.3. Unit Root Test

If the existence of CD is validated among the data, then it is important to perform second-generation unit root tests. For this purpose, we considered the cross-sectionally augmented IPS (CIPS), and cross-sectionally augmented DF unit root tests. These tests will evaluate the integration order of EF, RE, Governance, GDP, and ICT.

3.1.4. Cointegration Test

The study incorporates Westerlund [59] test to examine the cointegration among variables. The test provides robust outcomes even in the CD existence and overcomes the common factor restriction issues. The mathematical expressions for this test are:

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

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

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

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

$\partial^! = \frac{P_a}{T}$ represent the yearly ratio of correction.

3.1.5. Short- and Long-Run Analysis

Among the available econometric techniques, we incorporate the CS-ARDL approach by Chudik and Pesaran [60] to estimate the short- and long-run results. The model provides reliable outcomes even in the CD existence in the panel. Mathematically, it can be presented below:

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

Here, AEV and $Z_i = (\Delta EF_t\ AEV_t)$ represents a set of explanatory variables and the cross section averages, respectively.

3.1.6. Robustness Check Test

We continued to apply the augmented mean group (AMG), FMOLS, DOLS, and CCR methods to cross-check and ensure the robustness of the findings. These tests are valid because these tests tackle the CD and heterogeneity issues [61].

4. Results

Before performing the short- and long-run analysis, it is required to check for CD. Therefore, we applied the LM test, and the results are presented in Table 4.

Table 4. Results of CD analysis.

Variable	Test Statistics
EF	23.63 ***
ICT	37.30 ***
RE	40.99 ***
GDP	41.27 ***
GOV	40.92 ***

Note: *** = 1% significance level.

In the CD test, the *p*-value of EF, ICT, RE, GDP, and GOV is significant at a 1% level. This means that the variables of interest are moving equally, meaning that the variation among the data is quite similar. This outcome may be due to similar policies. To test the data heterogeneity, this work applied the slope test and reported the outcomes in Table 5. It indicates that the data are homogeneous at a 1% level. Next, the panel stationarity property is determined by CADF and CIPS tests, and the findings are in Table 6.

Table 5. Slope Test.

	Value	*p* Value
Delta	6.59 ***	0.00
adj	7.29 ***	0.00

Note: *** = 1% significance level.

Table 6. Unit root test.

Variable	CADF Test		CIPS	
	I(0)	I(1)	I(0)	I(1)
$lnEF_t$	−2.47	−4.43 ***	−2.79 **	−5.57 ***
$lnICT_t$	−2.92 **	−4.36 ***	−4.10 **	−6.04 ***
$lnRE_t$	−2.02	−4.04 ***	−2.14	−5.58 ***
$lnGDP_t$	−2.34	−3.55 ***	−1.94	−4.21 ***
$lnGOV_t$	−2.75 **	−4.27 ***	−2.97 ***	−5.55 ***

Note: *** = 1% and ** = 5% significance level.

Table 6 shows that the EF, ICT, RE, GDP, and GOV are integrated at first difference. It indicates a long-run association among the data. Next, to examine the cointegration among the data, we applied the Westerlund [59] test. This test by considering the CD in the data providing robust results.

The cointegration test outputs provided in Table 7 validate the strong cointegration among variables. Therefore, RE, government stability, EF, and GDP are moving together in the long run.

Table 7. Westerlund test.

Stat	Value	Z Value	*p* Value
G_t	−2.94 **	−1.73	0.07
G_a	−7.30 ***	2.44	0.00
P_t	−8.07 ***	−0.88	0.00
P_a	−6.34 *	1.29	0.09

Note: *** = 1%, ** = 5% and * = 10% significance level.

Next, the long- and short-run coefficient values of independent variables were estimated. To do this, we utilized the CS-ARDL method, and the findings of CS-ARDL are presented in Table 8. It shows that ICT is anticorrelated with EF. This means that a 1% upsurge in ICT will lower EF by 0.09% in the long run. Studies by Salahuddin et al. [53], Chien et al. [62], Zhang et al. [63], and Appiah-Otoo et al. [64] confirm the findings of this study. The long-run negative coefficient of RE and GOV is 0.12% and 0.05%, respectively, implying that they anticorrelate with ecological footprints. These results are supported by Yu et al. [65] and Lee [66]. A 0.07% coefficient value of GDP at a 1% significance level indicates the negative effects of GDP on environmental quality. The analyses by Lee [66] and Tariq et al. [67] are in alignment with the current study. The short-run estimations are consistent with long-run outcomes.

Table 8. CS-ARDL.

Short Run	Coefficient	ST Error	Prob
$\Delta lnICT_t$	−0.10 **	0.02	0.00
$\Delta lnRE_t$	−0.28 **	0.05	0.00
$\Delta lnGDP_t$	0.70 **	0.04	0.00
$\Delta lnGOV_t$	−0.09 ***	0.01	0.02
Long Run			
$lnICT_t$	−0.09 ***	0.01	0.00
$lnRE_t$	−0.12 ***	0.07	0.06
$lnGDP_t$	0.38 **	0.22	0.00
$lnGOV_t$	−0.05 **	0.01	0.00
ECM	−0.98 ***	0.06	0.00

Note: *** = 1% & ** = 5 significance level.

Apart from conducting the CS-ARDL, this work moves further to check the robustness of the findings. For this purpose, three tests are applied (FMOLS, DOLS, and CCR). Table 9 presents the findings of the robustness check, which validates the findings of the CS-ARDL. This means that our findings are robust and practicable for G11 countries.

Table 9. Robustness check.

Variables	AMG	FMOLS	DOLS	CCR
$lnICT_t$	−0.04 **	−0.03 **	−0.05 ***	−0.01 ***
$lnRE_t$	−0.02 **	−0.02 **	−0.01 **	−0.03 ***
$lnGDP_t$	0.45 ***	0.07 **	0.21 **	0.08 **
$lnGOV_t$	−0.01 **	−0.10 ***	−0.04 ***	−0.05 ***

Note: *** = 1% & ** = 5 significance level.

5. Discussion

The findings, as presented supra, mean that the use of internet services with other technologies is environmentally friendly in G11 nations. This outcome indicates that these countries are on the right track to adopting rapid communication technologies. This finding is supported by Khan et al. [52] for Morocco. The results also show that renewable energy is environmentally friendly. A 1% increase in RE lowers ecological footprints by 0.12%. RE is mostly coming from hydro, solar, and wind power. These sources do not contaminate the environment but help regenerate the natural habitat. These findings are similar to that of Naz et al. [68] for Pakistan, Pata [69] for Malaysia, and Sakodi and Adams [70] in South Asia.

The outcome also shows that GDP is linked directly with ecological footprints. This means that a 1% increase in GDP will increase ecological footprints by 0.38%. This means that G11 nations are consuming a high ratio of fossil fuels to achieve their economic goals. In pursuing their GDP growth, they are compromising the quality of the environment. This outcome is in line with the findings of Mehmood et al. [71].

The CS-ARDL results suggest that stability in government is negatively linked to ecological footprints. This means that a 1% increase in government stability lowers EF by some 0.05%. Government stability is not only linked with political stability. It is also about stability in institutions and other economic businesses. If the government make transparent policies for the welfare of the people, the citizen will respond positively to government policies which will enhance awareness in the environmental sector. This awareness would further enable the government to launch effective environmental policies. G11 countries are making progress in terms of political stability. This outcome is similar to the findings of Khan et al. [52].

6. Conclusions and Policy Implications

Climate change and global warming are due to the consumption of nonrenewable energy. G11 nations are facing environmental problems. Therefore, this study investigates the associations of RE, communication technologies, government stability, GDP, and ecological footprints in G11 countries. For econometric analysis, this work uses the annual data for the 1990–2020 period. This work applies second-generation methodologies to reveal robust results. The two tests of the unit root are applied and validate that none of the variables are integrated at the second difference. The CD test shows cross-sectional dependence among the panel data of G11 countries. After the confirmation of cointegration, this work moved forward to apply the CS-ARDL for short-run and long-run coefficient values. The findings show that RE, ICT, and government stability substantially reduce environmental pollution in G11 nations. These results confirm that G11 countries consume nonrenewable sources in the economic sector, which contribute to environmental pollution. Moreover, the role of government stability is essential for a cleaner environment. Therefore, policy makers need to bring policies that would make people adopt RE sources at industrial and household levels.

Lastly, this study has some limitations which can be considered in future research works. This work adopts a panel of G11 countries, and future works can utilize the time series data for a comparison of developing and developed countries. Such studies can add other variables of governance, such as accountability and corruption. Moreover, other variables of environmental pollution can also be utilized to study their linkages with ICT and governance. The model for future studies can also be developed by including other factors of research and development, environmental taxes, and green technologies.

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