

RESEARCH ARTICLE

The Interplay of Digitalization, Green Finance, and Institutional Quality in Overcoming Corruption's Impediments to Environmental Sustainability

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ABSTRACT

Green finance, digitalization, and institutional quality are fundamental in fostering a green transition for environmental sustainability. However, in the developing nations, corruption impedes the role of green finance and financial development from enhancing environmental sustainability in various ways. Corruption diverts and misappropriates green funds, weakens environmental governance and policy, distorts financial development for green growth, and erodes public trust and institutional capacity. This research examines the role of digitalization and institutional quality in advancing environmental sustainability, as well as addressing how high corruption impedes green finance from advancing a green transition. This research employs longitudinal annual data of the 15 West African economies from 2000 to 2022, which is analyzed with the Driscoll–Kraay method. The robustness of the findings is checked with the “Panel Correlated Standards Error” and “Feasible Generalized Least Square” methods. The research findings support that digitalization, institutional quality, and renewable energy support environmental sustainability. However, corruption impedes green finance and financial development on environmental sustainability in the developing nations. Therefore, this research calls for the developing nations to address the corrosive grip through anti-corruption measures, capacity building, policy reforms, and international cooperation.

1 | Introduction

Globally, and especially in emerging nations, environmental sustainability has grown to be a significant concern. The continuing dependence on fossil fuels to meet energy demands is the main source of ecological concern (Udeagha and Muchapondwa 2023). Around 75% of carbon dioxide emissions (CO₂e) worldwide are caused by the combustion of fossil fuels, making fossil fuel a major contributor to worldwide emissions of CO₂e (IEA 2020). Attempts to attain sustainable growth have been strained by the increase in the use of fossil fuel and the volatility of world prices for commodities, such as those of gold, which have worsened ecological impact (Xu et al. 2024). Issues like contaminants, abuse of resources, forest destruction,

climate change, and many more result in environmental deterioration. In light of these economic and environmental issues, a change to more ecologically friendly manufacturing and consumption methods is essential (Ali 2021; Arijeniwa et al. 2024). Green finance (GF), technological advancements, and digitalization, institutional quality (IQ), and financial development can be useful in achieving green transition. However, in the developing nations, corruption may impede green financial projects from enhancing environmental sustainability. Therefore, innovative research that addresses these barriers is required.

By increasing energy efficiency, technological developments significantly contribute to reducing environmental issues. Ahmad et al. (2023) alludes to the fact that technological

innovation (TI) is a key factor in advancing sustainable development as it boosts economic expansion without posing damage to the environment. One of the main drivers in boosting the economy is creativity in new technology, and technology may be used as a secret weapon in the fight against global problems (Xu, Salem, et al. 2022; Xu, Umar, et al. 2022). Technological advances and digitalization may reach consumers in three different ways—creation, diffusion, and innovation—that impact economic and environmental growth (Özkan et al. 2024). Energy is important in supporting the economic growth of nations, though it is important to understand and employ the energy types that do not degrade the environment (Murshed and Tanha 2021). Energy efficiency, alongside the use of clean energy such as renewable energy (RE), becomes the most crucial strategy to lower greenhouse gas emissions (GHGe) (Özbuğday and Erbas 2015; Akram et al. 2020). Energy efficiency programs may alleviate power shortages, decrease the environmental effect of CO₂e, increase energy security, decrease dependency on fossil fuels, improve ecosystem sustainability, and increase industrial rivalry by lowering operational costs (Akram et al. 2020). In order to lower CO₂e, energy utilization is a major problem in emerging nations; thus, technical innovation is necessary. Furthermore, natural resources (NRs) and their rents, such as natural resources rents (NRRs), can also promote a healthy environment (Deka 2024). It is unclear, nonetheless, if NRs can be relied upon to promote sustainable development, given the existence of two conflicting hypotheses about their function in sustainability (Shuayb et al. 2024). Additionally, the growing quantity of human activities that are adversely damaging the environment in Africa has lately raised concerns throughout the world (Bugri 2008).

Therefore, this research aims to examine the connection between digitalization, IQ, financial development, and GF in advancing environmental sustainability, particularly in West African economies. Previous research has shown that digitalization and GF are crucial in reducing environmental damage. Innovations in solar and wind energy technologies have made RE more competitive in comparison to fossil fuel (Tariq et al. 2024). Moreover, GF mechanisms, such as green bonds and sustainable investment funds, have been recognized as essential for funding RE projects, especially in developing countries (Sahoo et al. 2024). There is limited research showing that corruption in developing nations may impede GF projects and financial development from supporting environmental sustainability. IQ becomes key in ensuring the embezzlement of green funds is reduced and the implementation of environmental policies is maintained. Wang et al. (2021) demonstrate that the effect of government interference on pollution efficiency is consistent with the “promote first, inhibit later” characteristic when it is maintained as a threshold variable. Therefore, there is a need to investigate how robust environmental policies are and how the Government may engage in policy reform to support environmental sustainability.

This study adds to the growing body of knowledge by considering an analysis of the West African economies—the ECOWAS—that have high corruption, to understand the impediments of corruption on GF projects toward achieving environments. Therefore, the originality of this research is in threefold; first, it shows that GF projects and financial

development that are known to support environmental sustainability (Jarijari et al. 2025a, 2025b) are hindered by high corruption in the ECOWAS countries. Second, this research shows that strong IQ becomes the major driver of achieving environmental sustainability—calling for policy, strict monitoring of green financial projects, and the enforcement of environmental regulations. Third, this research shows the importance of digitalization and RE in achieving environmental sustainability in the ECOWAS countries. The major research questions answered in this study are; what is the role of digitalization and RE projects in environmental sustainability in nations that have high corruption? How does corruption deter green financial projects and financial development from supporting environmental sustainability, and what policy action can be taken to correct this problem? Is IQ effective in supporting environmental sustainability by ensuring GFs are not embezzled and environmental policies are correctly enacted and enforced? This research answers these research questions and contributes to the literature by employing the data of the ECOWAS countries from 2000 to 2022. Moreover, this research contributes methodologically by employing the contemporary Driscoll–Kraay method that overcomes “cross-sectional dependence” (CD) and serial correlation (Driscoll and Kraay 1998). Additionally, in order to ensure the robustness of the Driscoll–Kraay findings, the “Panel Correlated Standard Errors” (PCSE) and “Feasible Generalized Least Squares” (FGLS) methods are employed following recent studies of Deka et al. (2025).

The following section is dedicated to providing the review of literature, thereby analyzing the findings of past studies. This enables the identification of key research gaps that need to be addressed. In the third section, the research model is developed, following the various key theories of sustainability. Data collection procedures are explained, and the methodology of this study in finding the study findings is explained. In the fourth section, the findings of the study are explained and discussed in line with past empirical findings. In the last section, the conclusion is given along with the study implications.

2 | Literature Review

2.1 | Digitalization, Technology, and Environmental Sustainability

TI and digitalization are very important in achieving environmental sustainability, as evidenced in recent empirical evidence from the studies of Deka et al. (2025) and Jarijari et al. (2025a, 2025b). However, Sharma et al. (2021), Gyamfi et al. (2022), and Fu et al. (2018) believe TI has a contrary impact on the environment; thus, the effect of TI on sustainability is still unclear. According to Ahmad et al. (2023), TI is a key factor in advancing sustainable development, as it boosts economic expansion without having a negative impact on the environment. Bresciani et al. (2021) show that for a country to develop and grow, innovation and environmental sustainability are needed. Appiah et al. (2023) show that in the OECD countries, the quality of the environment itself is enhanced through TI. It is through TI that we came about RE. Empirical work alludes that RE negatively influences CO₂

emissions (Kahia et al. 2019; Habib et al. 2021). CO₂ emissions are considered the primary drivers of environmental degradation, climate change, and global warming. Shahbaz et al. (2015) mentioned that TI controls the decrease in energy consumption—improving energy efficiency—hence lessening CO₂ emissions and encouraging economic growth. Sahoo et al. (2023) found ICT to reduce CO₂e and improve the environmental quality in developing countries. They also found that the relationship between ICT and the control of corruption (CC) is positive for environmental sustainability. Behera et al. (2025) on E-7 countries found ICT to negatively influence CO₂e, which means it reduces it; but this effect is insignificant, meaning it has the potential of reducing CO₂e, but its impact in the E-7 countries is limited.

Empirical evidence is available, though limited, suggesting that TI is a key driver behind reduced environmental degradation. Wang et al. (2021) found that the effect of technological progress on CO₂ emission reduction in China is significant, and the effect of technological progress on improving energy efficiency is also significant. Similarly, Appiah et al. (2023) shows that TI improved the environmental quality through pollution abatement in OECD countries. Likewise, Deka et al. (2025) found TI to reduce CO₂e in the 10 NRs-rich African nations. While other studies have shown that TI is essential in the attainment of ES, other studies have shown that TI may not necessarily raise ES in other nations with poor IQ or weak green technologies. Sharma et al. (2021) and Gyamfi et al. (2022) argue that some innovations raise energy use, which negates their environmental gains. This uncertainty also indicates that technology in itself cannot be a solution, as severe regulations and market incentives are also needed. Jarjari et al. (2025a) supports this by showing that in the Sub-Saharan African (SSA) nations, TI increases ecological footprint (EFP); hence, decrease ES. Jarjari et al. (2025b) also supports the detrimental effects of TI on ES in the BRICS countries, by showing that TI reduces the load capacity factor (LCF).

Therefore, with the presence of diverse findings in the literature on how TI affects ES, there is a need for more studies to be done in order to fully understand this association; hence, devise proper policies toward enhancing ES. This research, therefore, adds to the growing body of literature by examining how digitalization (which focuses on the specific digital technologies) affects ES in the ECOWAS nations. Empirical evidence that covers the whole of SSA nations is presented in the recent studies of Jarjari et al. (2025a), empirical studies that focus on the specific sub-regions of Africa, like the ECOWAS, are lacking. This research extends the growing body of literature by investigating how digitalization affects ES in the ECOWAS countries, enabling policies that are specific to the ECOWAS countries to be devised.

2.2 | Institutional Quality, Trade Openness, and Environmental Sustainability

Governments can achieve environmental sustainability if strong governance structures and policies are established. Edeme and God (2022) allude that corruption, weak

governance, and ineffective regulations often hinder efforts to make Africa more sustainable. Such a development is particularly germane to ECOWAS, where institutional weaknesses are a big driver of environmental degradation. Institutions are essential to a nation's development and pollution release mitigation (Obobisa et al. 2022). The literature is still being explored, and the theoretical viewpoints and empirical data about the connection between institutions and pollution are primarily inconclusive, said (Jiang et al. 2022). According to recent proposals, a nation's political institutions determine its environmental quality regardless of its economic standing since pollution levels rise in nations with less effective environmental laws (Egbetokun et al. 2020). The quality of institutions can aid in environmental preservation measures that reduce CO₂ emissions and improve the ecological condition, in addition to creating technical advancements connected to the environment (Obobisa et al. 2022). According to Jarjari et al. (2025b), IQ is observed to promote ES in the BRICS nations, but only in the SR, meaning IQ will only enhance the environment if the nation has a lot of environmental issues. Results of Haldar and Sethi (2021) indicate that environmental governance and institutional excellence decrease emissions. Moreover, Muoneke et al. (2023) show that poor governance promotes environmental deterioration. This is also supported by the postulations that show that major pollution control could be improved by government interventions (Wang et al. 2021). Sethi et al. (2024) also got similar results and stated that strong IQ is generally associated with better ES as they ensure that there is implementation of sustainability policies. Indeed, there is some variation by country in institutional effectiveness. Corruption often hampers the effectiveness of governance leaning on sustainability in ECOWAS (Edeme and God 2022). Very few studies across ECOWAS have focused on IQ and its impact on ES. Research on effective governance structures that promote sustainability in the region is still lacking. Governments in ECOWAS should strengthen IQ by addressing issues of corruption, enforcing environmental laws, and increasing transparency. Good institutions also enable effective enforcement that can help achieve and realize positive fund trends as well as TI, thus improving environmental quality. Institutional strength is the bedrock of effective environmental governance.

Trade openness is another important factor that could support ES when accompanied by robust policies. According to Managi et al. (2009), minimum environmental efficiency can be obtained through trade openness that helps countries access green technologies. Additionally, Deka et al. (2025) also observed that trade openness could significantly decrease CO₂ emissions in the 10 NR-rich African countries. Conversely, Mrabet et al. (2021) claim that trade has a tendency to increase energy consumption and pollution, particularly in areas where regulatory structures pertaining to environmental issues are relatively weaker. Trade liberalization has both beneficial and harmful effects on the environment. Wang and Zhang (2021) assess the relationship between trade openness and CO₂ emissions in 182 economies from 1990 to 2015 and show that both high- and middle-income nations can lower their CO₂ emissions. In nations with lower-middle incomes, the impacts of trade openness are negligible but worsen. Furthermore, sustainable trade approaches are essential for

lowering ecological expenses linked to pollution from fossil fuels, according to Zuo et al. (2023). Trade openness could give ECOWAS access to clean energy technologies but also opportunities for unsustainable resource extraction in the case of weak institutional controls.

2.3 | GF, RE, and Environmental Sustainability

GF is important for RE project funding. Jarjari et al. (2025a) show that GF reduces EFP in the SSA nations, making GF an important variable in encouraging environmental sustainability. Additionally, Tariq et al. (2024) and Sahoo et al. (2024) postulate that GF mechanisms (green bonds, etc.) support a sustainable environment. However, the empirical evidence shows that the impact of GF is higher in the short run. According to Zhang et al. (2022), GF supports financial choices that support environmental preservation and the elimination of environmental degradation from corporate activities. Behera, Behera, and Sethi (2024) found that GF increases ES, especially through funding projects that reduce CO₂, and this is supported by the evidence of the empirical study by Sethi et al. (2024). Usman et al. (2022) discover that resource-rich nations may lessen their ecological impact by pursuing financial prosperity. Utilizing panel regression analysis and data collection from Indian states, Nenavath and Mishra (2023) examine how green financing affects sustainable economic growth in India. They emphasize the significance of GF in enhancing the efficiency and structure of the financial system. Behera, Behera, et al. (2024) documented that green TI improves environmental quality in BRICS countries. Studies on the structural barriers to GF are limited. Further studies should deal with financial policies that be adopted, especially in the developing nations where corruption could impede green financial projects from supporting ES, to ensure its effectiveness.

RE is also vital and has become an attractive topic due to the climate change that the world is facing now. The reason we face a lot of climate change is because of the amount of CO₂ emission being released from fossil fuel; hence, the reason to transition to RE consumption. RE is a clean, more dependable energy source, helps to drive the economy, enhances energy security, and protects our environment. Dong et al. mention that RE is not limited in contrast to fossil fuel and will not finish just by production and consumption. Studies such as Alola et al. (2023) argue that the energy-mix efficiency innovations have implications for reducing carbon footprint in the Nordic countries, while Pata (2024) stresses that favorable energy policies are paramount for the development of RE and energy efficiency technologies. Zhao et al. (2025) show that intelligent transportation systems, usually using renewables, have the potential to significantly decrease CO₂e, as evidenced in China. Behera, Behera, and Sethi et al. (2024) and Behera et al. (2025) found RE has a negative effect on CO₂e in emerging countries and E7 countries. This means that RE assists countries in achieving environmental sustainability. Behera, Behera, Sethi et al. (2024) also found the same results in the case of OECD countries. Guo et al. provide that the oil catastrophe of 1973 and concerns about the environment have caused people to focus on RE. Jarjari et al. (2025a) reported that the transition to RE sources reduces EFP in the SSA

nations. The same results were reported in the case of EU countries where RE reduces EFP (Deka 2025; Deka et al. 2025). Sethi et al. (2025) found that RE positively influences ES as it reduces EFP in BRICS countries. The application of RE is, therefore, affected by how the NRs are exploited (Han et al. 2023). However, Dong et al. highlight the gap between economic growth and emissions reduction, and they call for balanced policies. Behera, Sucharita et al. (2024) mention that although hydro is a renewable source, its presence in India causes biodiversity loss and human displacement, which degrades the environment and then slows down economic development. Liu et al. (2020) and Zhang et al. (2013) stress the need for consistent RE policy and industrial strategy to achieve the greatest environmental benefit. RE is essential to ES objectives, but will only be successful if accompanied by sound policy, TI, and institutional support.

3 | Research Framework and Methodology

3.1 | Research Design and Model

This research employs the “Resource Based View” (RBV) (Barney 1991) and the “Ecological Modernization Theory” (EMT) in determining the key factors essential in determining ES among economies (Mol and Spaargaren 2000). The RBV theories stipulate the importance of the resources available in the nation in fostering development (Barney 1991; Zhao et al. 2025). Key resources in an institution or economy, identified in previous studies, include technological resources, human capital, financial resources, and information (Wong et al. 2012). The EMT also points to the importance of policy frameworks, coupled with technological and institutional innovations in advancing the sustainability of economies (Lemprière 2016; Toke 2011). The EMT therefore alludes that for sustainability to be achieved, a multifaceted approach that integrates technology, innovation, market forces, and institutions is essential (Xie et al. 2022). Therefore, following the postulations of the RBV and EMT theories, this research adopts digital technology, GF, RE, IQ, and FD as the key resources and/or mechanisms that are necessary in advancing ES. This aligns with recent models developed in the contemporary studies that have been done in recent years (Deka 2023, 2024, 2025; Jarjari et al. 2025a, 2025b; Shuayb et al. 2024). Therefore, the research model of this study is presented in Equation (1) and this is the first model to be analyzed in this research.

Model 1:

$$LCF_{it} = \beta_0 + \beta_1 DIG_{it} + \beta_2 \log GF_{it} + \beta_3 RE_{it} + \beta_4 IQ_{it} + \beta_5 FD_{it} + \mu \quad (1)$$

where LCF is the load capacity factor representing the dependent variable of environmental sustainability. DIG, GF, RE, IQ, and FD are the independent variables and they mean digitalization, GF, RE, IQ, and financial development, respectively. Superscript *i* represents the number of “cross sections” that is the 15 ECOWAS countries employed in the data of this research, while superscript *t* the time frame of the data, which is from 2000 to 2022. The term log means the variable in question is transformed into logarithm form at base 10 in order to standardize the data. Moreover, β_0 is the constant of the model; β_{1-5} are the model parameters representing the coefficients of

all the independent variables; μ is the white noise error term of the statistical model catering for all peripheral variables that has been omitted in the model for various reasons such as data unavailability or because the impact of the variable in question is too small.

3.2 | Data

The data used in the analysis of this research is of the 15 West African nations, commonly known as the ECOWAS countries, that is, Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Sierra Leone, Senegal, and Togo. Moreover, the data used in this research is annual data stretching from the year 2000 to 2022. The data is retrieved from various databases; for instance, the data of EFP and biocapacity (BC) is retrieved from the global footprint network (GFN), GF from Our World in Data (OWD), and FD from the International Monetary Fund (IMF). Moreover, the data of internet users (IU), RE, government effectiveness (GE), mobile cellular subscription (MCS), and CC is retrieved from the World Bank (WB).

This research use the LCF as the dependent variable of environmental sustainability and is calculated as the ratio of BC and EFP. BC represents nature supply, that is, the resources available for use, while EFP represents nature demand, that is, the area needed to support human activities and to assimilate waste dumped into the environment. Therefore, an increase in the LCF means advancements in environmental sustainability, while a decrease in the LCF means environmental deterioration. The GF indicator employed in this research is the amount of funds in U.S. dollars given to developing nations in support of R&D projects on clean energy and technologies, Our World in Data (2025). Therefore, in increase in the GF will improve the clean technologies and energy of countries; hence, environmental sustainability is achieved (Jarijari et al. 2025a). Digitalization index employed in this research is calculated from two dimensions of IU and MCS with the “Principal Component Analysis” (PCA) following the studies of Deka et al. (2025). Improvements on digitalization means enhancement in the TI and thus environmental sustainability is achieved (Deka 2024). RE mean the clean energy sources such as solar, wave, wind and tidal among others that does not pollute the environment; hence, support environmental sustainability (Deka et al. 2025). FD used in this research is an index that represents the depth, efficiency and strength of the financial institutions and markets in an economy. Improved FD level enables the economy to finance the development of clean technologies and energy and achieve environmental sustainability (Jarijari et al. 2025b). IQ represents the efficiency and effectiveness of the Government in making and enforcing environmental regulations. The IQ index used in this study is calculated with the PCA methods from the GE and CC factors. IQ is important in ensuring the GF and other financial resources allocated toward green technological development are used for the right purpose. The measurements of the variables and their sources are summarized in Table 1 and the measures of dispersion and central tendencies are summarized in Table 2.

TABLE 1 | Variables summary.

Variables	Source	Measurements
Load capacity factor (LCF)	GFN	Ratio of BC and EFP gha per capita
Green finance (GF)	OWD	International funds for R&D on clean technologies and energy
Digitalization (DIG)	WB	PCA calculated index using MCS per 100 people and IU as % of population
Renewable energy (RE)	WB	% of total energy used
Institutional quality (IQ)	WB	PCA calculated index of GE and CC measured as ranks from −2.5 to 2.5
Financial development (FD)	IMF	Index on the financial strength, efficiency and depth of financial institutions and markets

3.3 | Method

The method of analysis employed in this research is the Driscoll–Kraay technique that is credited to the work of Driscoll and Kraay (1998). The Driscoll–Kraay method is employed in this analysis because it is a “second-generation” (SG) method, with the ability to solve the problems of CD and serial correlation in the model. Therefore, this research employs the pretesting methods to understand the nature and state of the dataset employed before selecting the appropriate method to be used for the analysis. Pretesting methods are essential in determining the suitable method of analysis, and recent studies have adopted this approach (Jarijari et al. 2025a, 2025b).

Firstly, the data is checked for CD with the Pesaran (2004) method and the model with the Friedman (1937), Frees (1995, 2004), and Pesaran (2015) techniques. The presence of CD in the variables and model, as shown in the results presented in Table A1 in the Appendix A, supports the adoption of the Driscoll–Kraay method that overcomes this issue. Secondly, the use of the Driscoll–Kraay method is supported by the presence of “heterogeneity” in the model, as shown by the Pesaran and Yamagata (2008) “slope heterogeneity” results in Table A1. Third, the “order of integration” of the variables is determined by the “Cross-sectional Augmented Dickey Fuller” (CADF) method that overcomes CD present in the variables (Pesaran 2007), and the results presented in Table A2 in the Appendix A depict that mixed “integration orders” are present in the variables; hence, the use of the Driscoll–Kraay method is supported. Fourth, the presence of a “long run” (LR) relationship in the model, as indicated by the Kao and Pedroni results in Table A4 in the Appendix A, calls for the need to use a method that presents LR results that are key for policy implications. Fifth, the

model specified in this research is suitable for the analysis because “multi-collinearity” issues are not present in the independent variables, as shown by the “Variance Inflation Factor” (VIF) method in Table A3.

This research also goes a step further in ensuring the results presented by the Driscoll–Kraay method are robust. Robustness checks are important in ensuring the reliability of the findings. To this end, two methods are employed to ensure the robustness of the results of the Driscoll–Kraay method. Therefore, PCSE of Beck and Katz (1995) and FGLS of Aaitken (1935) follow the recent studies that have employed the same methods because of their ability to overcome CD and serial correlation issues (Deka et al. 2025).

4 | Results and Discussion

The major findings of this research are presented in Table 3, according to the Driscoll–Kraay, PCSE, and FGLS methods employed. It is observed that the effects of digitalization in

affecting environmental sustainability are positive and significant. The findings show that if digitalization is raised by 1 unit, the LCF increases by a magnitude of 0.029 units, according to the Driscoll–Kraay method. The PCSE and the FGLS results also support the results of the Driscoll–Kraay by showing that digitalization's effect on LCF is positive and significant at 1%. The PCSE results show that if digitalization is increased by 1 unit, the LCF will increase by 0.39 units, and the FGLS also shows that LCF will increase by 0.1739 units. These results portray the importance of digitalization in increasing LCF; thus, it increases ES in the ECOWAS countries. The findings presented here align with past literature, showing that digitalization supports ES (Raihan et al. 2022; Ahmad et al. 2023; Bekun 2024). Further, empirical evidence also supports these findings by showing that TI enhances ES (Manu et al. 2024; Hassan 2023). Specifically, Deka et al. (2025) supports this notion in the case of 10 NR-rich African countries, where the study observed the importance of TI for a sustainable environment. Therefore, the ECOWAS countries could benefit from achieving a sustainable environment through digital technologies adoption.

TABLE 2 | Descriptive statistics.

Variable	Obs	Mean	Std. dev.	Min	Max
BC	345	1.3767	0.9316	0.4373	5.1641
EFP	345	1.2283	0.2522	0.7782	2.1091
MCS	345	52.8868	40.9248	0	141.6399
IU	345	12.1725	15.5021	0.0177	70.3561
RE	345	68.6453	19.4151	20.78	94.42
CC	345	−0.5991	0.5396	−1.5974	1.1271
GE	345	−0.8144	0.4443	−1.8074	0.3409
GF	345	56,200,000	308,000,000	0	515,000,000
FD	345	0.1144	0.0509	0.0308	0.2960

TABLE 3 | Driscoll–Kraay, PCSE and FGLS results.

	Coef.	Std. err	p	Coef.	Std. err	p
	<i>Driscoll–Kraay</i>			<i>PCSE</i>		
DIG	0.0298c	0.0171	0.096	0.2261a	0.0395	0.000
lnGF	−0.0092a	0.0017	0.000	−0.0025	0.0039	0.523
RE	0.0086a	0.0021	0.001	0.0153a	0.0013	0.000
IQ	0.0622a	0.0177	0.002	−0.1602a	0.0347	0.000
FD	−2.2502b	1.057	0.045	−5.4050a	0.4809	0.000
	<i>FGLS</i>					
DIG	0.1739a	0.0243	0.000			
lnGF	0.0014	0.0025	0.564			
RE	0.0142a	0.0015	0.000			
IQ	−0.0715b	0.0306	0.019			
FD	−5.0671a	0.4621	0.000			

Note: Letters a–c show the level of significance at 1%–0%.

Moreover, the results of the Driscoll–Kraay show that RE's effect on the LCF is positive and significant at 1%. The results show the importance of RE in increasing LCF; hence, ES is raised. It is observed that raising RE use by one unit is associated with increasing LCF by a magnitude of 0.0086 units. The PCSE and the FGLS results support the results of the Driscoll–Kraay by showing positive and significant results. The PCSE results show that if RE is increased by 1 unit, the LCF will increase by 0.0153 units and by 0.0142 units according to the FGLS method. These results portray that RE is important in increasing LCF, which promotes environmental sustainability in the ECOWAS countries. These findings are supported by the results of past empirical evidence that has shown the importance of RE on ES (Aquilas et al. 2024; Ali and Yu 2021; Alam et al. 2024; Mperejekumana et al. 2024; Nketiah et al. 2022). Therefore, RE development policies in the ECOWAS countries are crucial in ensuring a green transition that leads to the achievement of a sustainable future.

Additionally, this research presents the importance of IQ in improving LCF in ECOWAS countries. The Driscoll–Kraay findings show positive results of IQ that are significant at 1%. Specifically, the Driscoll–Kraay method depicts that a 1-unit increase in IQ leads to a 0.06 units increase in the LCF. The PCSE and the FGLS results do not support the results of the Driscoll–Kraay test by showing a negative effect that is significant. The PCSE results show that if IQ is increased by 1 unit the LCF will decrease by 0.16 units and the FGLS show that the LCF will decrease by 0.07 units. This effect could be as a result of high corruption in the SSA countries. Deka et al. (2025) highlights the importance of IQ through improved governance in the attainment of ES. Many other empirical studies have supported the importance of strong institutions that include good governance and GE in supporting ES (Safdar et al. 2022; Traoré et al. 2024). Therefore, the present study calls for the ECOWAS nations to strengthen institutions and the level of governance in order to ensure correct environmental policies are enacted and followed. Strong institutions can also be beneficial in lowering corruption that could lead to the embezzlement and misuse of green funds.

Consequently, the results in Table 3 show that the effects of FD on ES are negative and significant at 5%. This implies that FD decreases LCF; hence, decreases ES. The Driscoll–Kraay method shows that if FD is increased by 1 unit, the LCF decreases by a magnitude of 2.25 units. The PCSE and FGLS results support the results of the Driscoll–Kraay test by showing the negative and significant relationship. The PCSE results show that if FD is increased by 1 unit, the LCF will decrease by 5.405 units, and the FGLS also shows that LCF will decrease by 5.067 units. The findings of this study show that FD strongly impacts the LCF to decrease in the ECOWAS countries. This is an indication that FD does not support ES; rather, it worsens the deterioration of the environment. FD should generally help in supporting ES through green funding and supporting RE development that leads to a green transition (Mukhtarov et al. 2022). Various empirical evidence depicts the importance of FD in supporting ES. For instance, Deka et al. (2025) and Jarijari et al. (2025a) found FD to reduce EFP in the context of SSA countries, but only in the SR. The unlikely results presented in this study are due to the high corruption in West African countries. Because of corruption,

funds that are meant to be used for environmentally sustainable projects are often misallocated, leading to less access to financial services, which is the whole aim of FD. Therefore, policy reforms targeting the efficient allocation of financial resources in this region could go a long way in ensuring ES is realized from FD.

Similar to the detrimental effects of FD on ES in the ECOWAS countries, GF is also observed to negatively affect the LCF. The Driscoll–Kraay method shows that GF has a significant and negative effect on LCF, which diminishes ES. If GF is increased by 1%, LCF will decrease by 0.0092%. The PCSE results support the results of the Driscoll–Kraay test by showing that GF is negative, though the influence is insignificant, and the FGLS results show positive but insignificant results. The PCSE and FGLS techniques show that GF does not influence ES in the ECOWAS countries, while the Driscoll–Kraay test depicts that GF reduces ES. Contrary to the results found in this study, Jarijari et al. (2025a) and Usman et al. (2022) found GF to greatly improve ES. The negative significant effects presented based on the Driscoll–Kraay method, which is a more robust method that overcomes CD and serial correlation, highlight the presence of corruption in impeding the influence of GF in advancing ES. In the West African region, funds meant for GF are misallocated, embezzled, and misused, making GF less effective.

5 | Conclusion

Although GF and FD are believed to help in sustainable development, their effectiveness when corruption exists is reduced. Corruption aids environmental crimes, undermines regulatory systems, and redirects resources from climate action and clean energy transition projects. In many countries with weak institutional systems and governance values, finance is misallocated, preventing welfare and decent progress in environmental sustainability. The empirical results from the Driscoll–Kraay, PCSE, and FGLS estimations provide important and major insights into the relationships between digitalization, GF, RE, IQ, FD with the LCF. Results of all methods reveal that RE has a positive and significant influence on ES. This confirms that RE would impact carbon reduction and supports biodiversity. TI had a positive and significant influence in the PCSE and FGLS results, with weak significance in the Driscoll–Kraay methods, implying innovation can aid sustainability as long as corruption does not wear down such impact. IQ yields conflicting results, positive and significant under the Driscoll–Kraay method and negative and significant under the PCSE and FGLS methods. This is possibly due to institutional contradictions or regional differences. GF and FD are observed to reduce the LCF, suggesting that in the absence of some effective anti-corruption initiatives, GF and financial development may not yield positive environmental gains. GF and FD have great potential in terms of contributions to environmental sustainability if managed properly. The negative coefficient of FD in every model and the inconsistent effects of GF suggest that in the presence of corruption, financial mechanisms can be used as exploitative instruments rather than transformative processes. That is, GF can become enslaved to elites or is often diverted into greenwashed projects, which do not fulfill environmental goals. Similarly, FD

can provide access to credit and capital in ways that consistently support industrial pollution or new environmentally degrading activities in the absence of regulatory oversight. The practical success of GF and FD as tools for sustainability depends on the quality and transparency of institutions. Future studies should pursue an analysis of the relationship between corruption, GF, and environmental performance by directly incorporating corruption indices and different conceptual components of GF such as green bonds and green loans. Although RE and TI provide some hope of progress, their success is weak without solid, transparent institutions that operate effectively. The analysis suggests that increasing financial flows and stimulation of innovation are insufficient in rooting out corruption; without reforming governance and accountability, these economic mechanisms can spread a condition where environmental effects can be expanded. Strengthening governance and accountability is the only way that finance could end up being a factor for environmental good rather than environmental harm.

5.1 | Policy Recommendations

- Developing a strong GF system by using greener financial systems such as green bonds and sustainable investment funds will greatly promote ES.
- Improving governance and strong IQ through the eradication of corruption and holding those that practice it accountable is very important to ensure effective implementation of sustainability policies.
- Employing long-term strategies by incorporating sustainability into national development goals, for example, by using models of the open economy, long-term ecological and economic benefits may be guaranteed.

Author Contributions

Abraham Deka: conceptualization, methodology, formal analysis, visualization. **Ummukhulthum Adamu Ibrahim:** writing – original draft, writing – review, Conceptualization. **Huseyin Ozdeser:** supervision, editing, investigation.

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Appendix A

TABLE A1 | CD and heterogeneity results.

Variable	Statistic	<i>p</i>		Statistic	<i>p</i>
	Pesaran (2004)		Friedman (1937)	28.087b	0.0139
LCF	33.78a	0.000	Pesaran (2015)	1.848c	0.0647
TI	29.89a	0.000	Frees (1995, 2004)	1.650a	
lnGF	13.88a	0.000			
RE	17.86a	0.000			
				<i>Heterogeneity</i>	
IQ	−0.51	0.612	Δ	6.080a	0.000
FD	25.19a	0.000	Δ adj.	7.299a	0.000

Note: Letters a–c show the level of significance at 1%–10%.

TABLE A2 | CADF results of UR.

	Level		1st D	
	Statistic	<i>p</i>	Statistic	<i>p</i>
LCF	−2.838a	0.000		
TI	1.887	0.970	7.405a	0.000
lnGF	−3.766a	0.000		
RE	−2.155c	0.062	−3.920a	0.000
IQ	−2.791a	0.000		
FD	−2.652a	0.000		

Note: Letters a and c show the level of significance at 1% and 10%.

TABLE A3 | VIF results.

Variable	VIF	1/VIF
RE	3.09	0.3232
IQ	2.82	0.3544
DIG	1.92	0.5221
FD	1.68	0.5951
lnGF	1.08	0.9223
Mean → VIF	2.12	

TABLE A4 | Cointegration results.

	Statistic	<i>p</i>
Kao test		
Modified DF	0.2529	0.4002
DF	−0.9232	0.1780
ADF	1.2443	0.1067
Unadjusted modified DF	−2.2707b	0.0116
Unadjusted DF	−2.6044a	0.0046
Pedroni test		
Modified PP	2.9111a	0.0018
PP	−3.1124a	0.0009
ADF	−3.4591a	0.0003

Note: Letters a and b show the level of significance at 1% and 5%.