Renewable energy consumption, financial assistance, and eco-economic sustainability in developing countries

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Abstract

Sustainability remains a major challenge for developing economies, where efforts to promote economic growth must be balanced with environmental protection. This study examines the impact of renewable energy consumption on economic and environmental sustainability in developing countries and investigates whether financial support strengthens these effects. Using panel data for 107 developing countries over the period 2000–2023, the study evaluates the relationships among renewable energy consumption, economic growth, and CO_2 emissions. It examines the moderating roles of foreign direct investment (FDI) and green finance. The findings indicate that renewable energy consumption significantly reduces CO_2 emissions, thereby contributing to environmental sustainability, but is associated with a negative effect on economic growth. Further, financial support significantly moderates the relationship between renewable energy consumption and sustainability outcomes. In particular, FDI and green finance strengthen the emissions-reducing effect of renewable energy while also amplifying its negative association with economic growth. These findings highlight the importance of designing financial and policy frameworks that facilitate renewable energy transitions while addressing their potential short-term economic costs. The study contributes to the sustainability literature by demonstrating that the effectiveness of renewable energy consumption depends not only on its direct environmental benefits but also on the financial conditions under which the transition occurs in developing economies.

Keywords: *Renewable energy consumption, Sustainability, Financial decision-making, FDI, Green finance*
JEL Classification*: L26; M13; O10; O53*

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1. Introduction

Eco-Economic sustainability (ECOSUS) has emerged as a major policy concern for developing economies experiencing rapid industrialization, rising energy demand, and environmental pressures. Conventional growth paradigms in these nations have largely depended on fossil fuels, leading to increased greenhouse gas emissions, environmental degradation, and susceptibility to fuel price fluctuations. Renewable energy (RE) usage has become one avenue through which sustainable development can be promoted by balancing economic growth and environmental protection goals.

RE is also considered part of long-term economic performance in addition to being an environmental solution. The available literature confirms that the use of renewable energy sources positively affects the economy by stimulating investment, innovation, and energy security (Kasperowicz *et al.* 2020; Simionescu 2023; Wang *et al.* 2022a). The experience of developing economies also indicates that the use of RE could help in eliminating energy deficits and reduce reliance on foreign fossil fuels, thereby contributing to economic growth (Hieu and Mai 2023).

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Nevertheless, current studies also indicate that the effects of RE growth are heterogeneous and depend on country-specific structural factors such as resource endowments, fossil fuel reliance, and institutional quality (Hwang and Sánchez Díez 2024; Wang *et al.* 2022b). These results suggest that RE is not always a reliable means of ensuring sustainable economic outcomes.

Next to the growth factor, environmental sustainability appears to be an urgent issue for developing countries, which now contribute significantly to global CO2 emissions (Abbasi *et al.* 2022). Practical evidence shows that the use of RE can reduce CO2 emissions, the ecological footprint, and CO2 intensity, thereby improving environmental quality (Chang *et al.* 2022; Guo *et al.* 2023; Lee *et al.* 2023; Raihan and Tuspekova 2022). Although these environmental benefits are well documented, a key question remains: how can they be translated into long-term economic sustainability (ECOSUS), ensuring that environmental gains contribute to sustained economic development without compromising environmental integrity or depleting natural resources?

Achieving ECOSUS requires an integrated approach that balances long-term economic growth, environmental protection, and the efficient and sustainable utilization of natural resources. RE consumption (REC) plays a dual role in the process: it promotes green productivity, increases energy security, and minimizes vulnerability to external shocks. Nevertheless, financial conditions are vital to determining the feasibility of RE in providing ECOSUS, and in developing economies, these conditions are usually limited. RE projects that require substantial capital usually demand significant financial resources, technology, and long-term investment time, which may not be available in domestic markets.

In that regard, such external financial assistance instruments as foreign direct investment (FDI) and green finance are especially significant. FDI also enables the flow of technology and managerial skills, provides access to global value chains, and strengthens the REC's economic integration (Doytch and Narayan 2016; Fan and Hao 2020). On the same note, green financial products help divert financing resources and investment risk toward RE and low-CO2 projects by lowering financing costs and investment risk (Du *et al.* 2024; Liu and Li 2025). While the direct impacts of RE, FDI, and green finance on growth and environmental performance are documented in the current literature, there is little focus on their interrelationships.

The majority of empirical studies consider RE, FDI, and green finance as independent factors of sustainability, without acknowledging that financial support can also precondition the efficiency of RE use. The gap is especially severe in developing countries, where sustainability outcomes are shaped by limited financial resources, institutional diversity, and unequal access to green technologies. It is thus important to know both whether and how the relevance of financial assistance enhances the nexus between RE and ECOSUS, so that effective policy interventions can be designed.

This study contributes to the literature on sustainable development in four main ways. First, by covering economic growth and environmental outcomes, it offers a more holistic view of the sustainability impact of renewable energy in developing economies, adding to the existing body of literature, which tends to focus primarily on either economic growth or environmental impacts. First, it fills a gap in the existing literature by covering both economic growth and environmental outcomes, thereby providing a more comprehensive assessment of the relationship between renewable energy consumption and the economic and environmental dimensions of eco-economic sustainability in developing countries. Secondly, it enriches the sustainable finance literature by examining the moderating effects of foreign direct investment and green finance, thereby

providing a deeper understanding of how financial support influences the effectiveness of renewable energy in achieving economic, social, and environmental goals. Third, it uses a large panel of 107 developing countries over the time horizon 2000-2023 and applies several estimation methods, such as fixed effects, random effects, and two-step system GMM, to mitigate unobserved heterogeneity and potential endogeneity and enhance the robustness of the empirical results. Lastly, the results offer policy-relevant lessons that show how REC can benefit the environment, yet can also entail economic trade-offs and underscore the importance of financial support for REC outcomes. These findings can inform policymakers in designing financial and energy policies to support renewable energy transitions better and achieve economic and environmental sustainability goals.

This manuscript is structured as follows. After this introduction, Section 2 presents the literature review, demonstrating the theoretical basis and prior research on the relationships among RE, ECOSUS, and financial support. Section 3 provides the research methodology, including data sources, variable definitions, and model specification. Section 4 gives the empirical results, which comprise descriptive statistics, correlation results, regression outcomes, and robustness tests involving system GMM. Section 5 concludes the study, summarizing major insights, contributions, and future research directions.

2. Literature review

2.1. Impact of renewable energy consumption on eco-economic sustainability

The relationship between the use of RE and economic growth has attracted increasing attention in the literature; most studies show a positive relationship, but the strength of the relationship and the transmission mechanisms vary across contexts. Drawing on substantial empirical evidence, Wang et al. (2022a) demonstrate that RE is an aspect of economic prosperity; it is not an environmental policy tool but a driver of growth. Their results can be summarized as follows: RE not only facilitates the achievement of sustainable development goals but also has a direct positive impact on the economy by investing in energy, developing innovations, and ensuring energy security. In line with this view, Kasperowicz et al. (2020) and Simionescu (2023) also indicate a positive and significant effect of the REC on the growth of living economies, supporting the view that RE has become a global economic commodity. These papers highlight that the introduction of RE into national energy systems has the potential to increase productivity and long-term growth, especially in countries with the right institutional and market settings. Nevertheless, these studies are affirmative in that they establish a relationship, but, to a large extent, they rely on aggregate-level analyses, which are likely to conceal country-specific heterogeneity.

The growth-enhancing effect of RE is also supported by evidence from developing economies. According to Hieu and Mai (2023), the use of Rpositively impacts economic growth in the developing world, suggesting that RE can help overcome energy shortages and reduce dependence on imported fossil fuels. Still, the potential of RE to drive growth requires additional variables to be considered, such as infrastructure quality, financial growth, and policy stability, which are not always evenly distributed across regions of developing countries. The current literature is enriched by Hwang and Sánchez Díez (2024), who show that the effects of the RE transition on growth are unequal. They find substantial positive effects of RE on green economic growth, although the effects differ significantly across geographic location, reliance on fossil fuels, and mineral endowments. This makes it clear that structural and resource-related factors play a

significant role in determining the economic payoff of consuming RE, implying that a universal policy solution might not be successful.

From a dynamic perspective, according to Saint Akadiri et al. (2019), REC has long-run causal relationships with economic growth, both positive and negative. Their results suggest that RE and economic growth mutually support each other over time, which proves that REC is not a result of economic growth but a cause of it. Their research is based on EU-28 countries and the mitigation of environmental pollution; however, they also give valuable information on the nexus of growth and the environment. Qudrat-Ullah and Nevo (2021) demonstrate that the use and development of RE are highly effective at boosting economic growth in both the long and short run in Africa. In addition to the increasing number of supporters of the beneficial nature of RE, much of the empirical data is focused on developed or region-specific settings. Emerging economies, which differ in institutional structures, cultural contexts, and environmental factors, remain underexplored. Given these structural differences, the growth impacts of REC may vary substantially across developing countries, warranting further empirical studies. According to the discussion above, the hypothesis is as follows:

H1: *Renewable energy consumption significantly affects the economic dimension of eco-economic sustainability.*

Climate change caused by greenhouse gas (GHG) emissions, especially CO2, is extremely dangerous to environmental quality, long-term development, and sustainability (Raihan and Tuspekova 2022). Global warming is one of the most urgent environmental issues worldwide, and international agreements, such as the Paris Agreement, focus on reducing emissions but acknowledge the significant contribution of developing economies to global CO2 emissions (Abbasi *et al.* 2022). In this regard, the use of renewable energy sources has become a major policy tool for environmental sustainability.

There is an accumulating amount of empirical literature on the environmental advantages of RE. As shown by Raihan and Tuspekova (2022), the REC is negatively and significantly associated with CO2 emissions, indicating that it can be effective in the fight against climate change. Similarly, Chang et al. (2022) identified the use of environmentally friendly energy sources as one of the main determinants of reducing the ecological footprint. They stated that clean energy sources could decouple economic activity from environmental harm. This progress has been added to the debate that RE sources are a significant factor in decreasing the strain on the environment.

This argument has been advanced in recent studies, which have investigated broader sustainability mechanisms. Jiang et al. (2024) present findings indicating that the most effective channel for enhancing green total factor productivity is energy optimization via RE. The long-run and short-run evidence also supports the argument for RE. Guo et al. (2023) affirm that the negative effect of REC on CO2 emissions in the short and long term is significant and substantial, underscoring the ongoing relevance of the environmental benefits of RE use. Equally, Usman et al. (2020) discover that REC, as well as real output, places negative pressure on the ecological footprint, implying that clean energy will be able to compensate for the environmental cost that is usually linked to economic growth. Further evidence is provided by Kirikkaleli and Adebayo (2021), who report a positive long-run impact of RE on environmental sustainability. Sharif et al. (2024) also show that RE will boost lo-factor capacity, thereby improving energy efficiency and reducing the ecological footprint. Regarding intensity levels, Lee et al. (2023) indicate that RE

development makes a considerable contribution to reducing CO2 intensity, and Li et al. (2022) affirm that RE makes a positive yet significant contribution to environmental issues and the long-term sustainability of the environment.

In addition to a positive shift in opinion regarding the environmental advantages of RE, much of the current literature on empirical evidence is concentrated on the developed or mixed-country sample, and little consideration is paid to the developing economies. The third world countries have their own set of challenges, such as high rates of industrialization, rising energy demand, lax law enforcement, and limited availability of green technology. These differences are likely to affect the REC's efficiency in enhancing environmental sustainability, leaving a gap in the literature that warrants targeted research. This gap is addressed by the current research, which examines how the use of RE will affect environmental sustainability in developing nations, where the transition to clean energy is both urgent and challenging. Consistent with the above discussion, the hypothesis is as follows:

H2: *Renewable energy consumption significantly affects the environmental dimension of eco-economic sustainability.*

2.2. Moderating role of financial assistance on the relationship between renewable energy consumption and eco-economic sustainability

Foreign direct investment is important in determining the success of RECs in realizing ECOSUS, especially in developing nations. In addition to its direct role in capital formation and economic development, FDI enables the transfer of technologies and managerial skills, and provides access to global value chains, all of which can determine how investments in RE translate into short- and long-term economic and environmental impacts (Doytch and Narayan 2016). As a result, FDI is increasingly accepted as a conditioning variable that can enhance the sustainability advantages of REC, contingent on the character and quality of investment inflows (Fan and Hao 2020). The development of RE involves substantial investment and a range of technologies, and FDI can provide the necessary finance and technology for this sector (Brunnschweiler 2010).

The literature also reports that FDI helps develop RE by alleviating financial strain and accelerating the diffusion of clean technology (Aust *et al.* 2020). FDI inflows play a very important role in financing large-scale RE projects and other infrastructure investments in developing economies, where domestic capital markets are underdeveloped. Another important role of external investment in developing countries is its contribution to industrial output growth, which will facilitate the sustainability of environment-related activities (Gusmão Caiado *et al.* 2018). The empirical evidence supports this complementarity. As demonstrated by Abbas et al. (2021), FDI plays an integrating role, whereby sufficient FDI flows significantly improve the use of clean energy and the efficiency of energy consumption. Consequently, FDI has played a key role in environmental rehabilitation and the region's sustainability, especially in Asia.

Beyond ecological effects, FDI has a profound impact on economic performance. According to Raihan et al. (2025), a 1% increase in REC and FDI leads to a 1.02% and 1.87% increase in GDP, respectively, indicating the growth-promoting effect of each factor. Likewise, Appiah-Otoo et al. (2023) conclude that the dependence between REC and FDI has a positive and significant influence on economic growth, indicating that FDI reinforces REC's impact on economic growth in West Africa. In addition to capital inflows, FDI enables knowledge transfer, managerial know-how, and research and development, thereby further improving economic

growth and productivity (Dankyi *et al.* 2022). This interaction implies that RE is more likely to improve the ECOSUS with high-quality FDI inflows.

As far as sustainability is concerned, the moderating effect of FDI is particularly significant, since economic sustainability requires the coexistence of long-term economic growth and environmental safety. Although the mechanisms by which FDI can be considered a moderating factor are theoretically crucial, empirical evidence on this concept is scarce, especially in developing-country settings. The majority of the current works were directed at the immediate influence of RE or FDI on sustainable economic development and environmental performance separately, without discussing their interdependence with each other explicitly. This is a promising research gap regarding the effects of FDI on the sustainability implications of RE development in developing economies, where institutional quality and investment patterns are heterogeneous. To bridge this gap, this paper will explore the moderating effect of FDI on the linkage between the REC and ECOSUS in developing nations. Based on this, it is suggested that the following hypothesis can be tested:

H3: *Foreign direct investment strengthens the positive impact of renewable energy consumption on eco-economic sustainability in developing countries.*

Green finance has become a critical tool for balancing environmental goals with ECOSUS over the long run, especially for the RE transition in developing nations (Han *et al.* 2025). The availability of green finance may be crucial to ensuring that the conversion of RECs into long-term economic and environmental benefits depends on the nature of the RE projects, especially capital-intensive ones. The transition to a low-CO2 energy system can be secured through green finance, improved resource allocation, further technological advancement, and policy coherence. As to efficacy regarding the allocation of capital, there exists a redirection of capital from CO2-intensive sectors to RE via the use of green finance instruments, such as green bonds, green credit, and green insurance, by decreasing the cost of capital in clean energy campaigns (Du *et al.* 2024; Liu and Li 2025).

It is also evident from the literature that green finance helps reduce financial barriers and investment risks for RE projects. In developing economies with short-term orientations to returns in conventional financial models, green finance can be used to reorient capital towards sustainable sectors, increasing the growth and productivity effects of the use of RE. Green finance is a critical element of sustainability, and its significance is empirically justified (Sun *et al.* 2025). Prior studies (Sun *et al.* 2025; Zhu *et al.* 2025) indicated that green finance is highly effective in mitigating the ecological footprint. In addition, Sharif et al. (2022) found that green financing enhances environmental sustainability by reducing CO2 emissions in G7 economies.

In addition, at the efficiency level, Huo et al. (2022) examine Chinese cities and find that green finance has an inhibitory effect on energy consumption, implying its potential to enhance energy efficiency rather than increase energy consumption. In addition to its environmental impact, green finance also plays a role in economic performance, which is key to sustainable development. Green finance drives economic growth in ASEAN economies, as demonstrated by Ngo et al. (2022), and is relevant to achieving both the economic and environmental dimensions of sustainability in the context of the Sustainable Development Goals in Indonesia, as highlighted by Ronaldo and Suryanto (2022). Zhou and Li (2022) evaluate the combined effect of green finance and RE on the sustainability process in China and conclude that ECOSUS is enhanced by the development of green finance. More recently, Wen *et al.* (2025) demonstrated that green

finance not only hastens the adoption of sustainable energy and reduces emissions but also boosts economic growth. In contrast, the direct effect of RE investments is to increase GDP and enhance environmental quality.

Green finance contributes to the sustainability of an economy by facilitating resource-intensive economic growth and structural change towards a low-CO2 economy. With green finance mechanisms supporting RE projects, there is a greater likelihood that projects will yield long-lasting economic benefits, including innovation, job creation, and enhanced energy security. Direct evidence of the positive effect of green finance on the REC, presented by Chen and Lubabu (2026), supports the complementary relationship between clean energy transitions and financial systems. In addition, green finance promotes private-sector involvement and attracts international capital, which is especially valuable to developing economies with fiscal constraints and technological gaps.

The majority of existing research treats both green finance and RE as independent variables that drive sustainability outcomes, without accounting for the fact that green finance can predetermine the efficacy of RE in providing long-term ECOSUS. This has been left out, particularly because, without the necessary financial support and the implementation of specific guidelines governing the use of RE, RE is unlikely to yield optimal sustainability outcomes. It is the moderating effect of green finance that comes into play, especially as a means of achieving ECOSUS; there should be a mix of economic growth, environmental protection, and economic stability. Green finance could help maximize the positive outcomes of the application of RE for the sustainability of the economy, namely, by making capital allocation more efficient, reducing the cost of building the financial base, and encouraging long-term investments. Moreover, emerging economies face various structural and policy challenges related to green finance and energy transitions. These obstacles are not only the consequence of financial and technological constraints but also of established socioeconomic orders and strategic directions that result from globalization (Kalinowski 2024; Sadiq *et al.* 2024). These homogeneous features of developing economies determine the effectiveness of green finance in facilitating the energy transition, with regional disparities in performance and unequal policy effectiveness. Hence, it is necessary to analyze this relationship in emerging economies, since their structural and institutional heterogeneity may contribute greatly to the importance of green finance in facilitating sustainable energy transitions. Based on the above discussion, the following hypothesis is suggested:

H4: *Green finance strengthens the positive impact of renewable energy consumption on eco-economic sustainability in developing countries.*

Figure 1 presents the theoretical framework developed from the relationships discussed in the literature.

3. Model specification and data

3.1. Data and variables

The paper investigates the immediate repercussions of renewable energy use on ECOSUS, with special attention to the moderating effect of financial aid. The panel data is analyzed for the period 2000-2023 and focuses only on developing countries. Although some data sources may contain information beyond 2023, the analysis is restricted to 2000–2023 to maintain a consistent observation period across all variables and countries and to avoid potential inconsistencies arising

from differences in data availability and reporting across sources. A balanced sample of 107 emerging economies is used, yielding 2,568 observations.

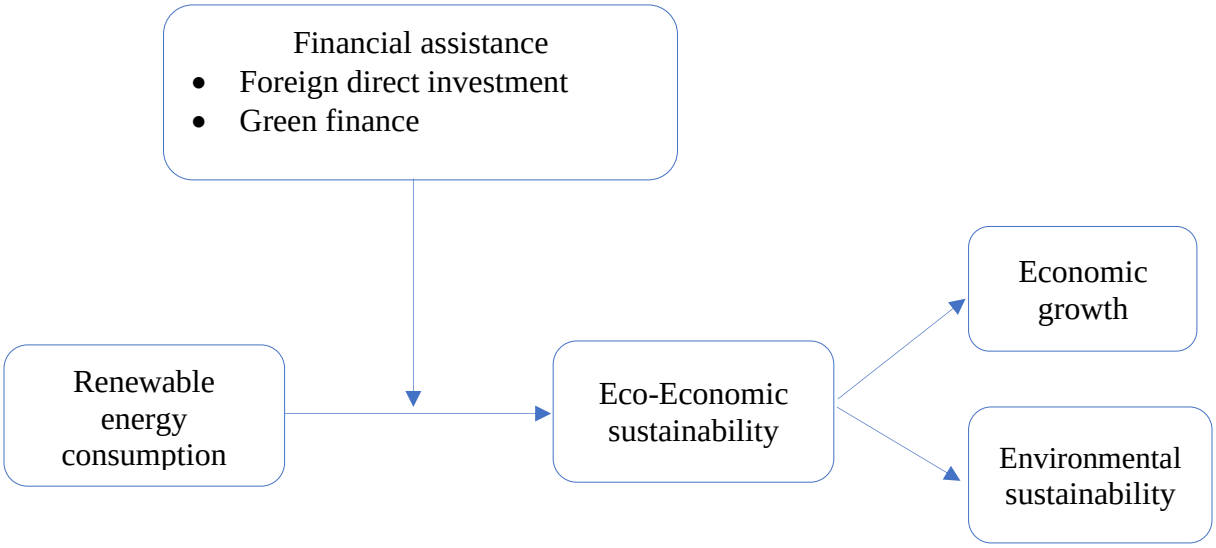


Figure 1. Conceptual framework of the study

Developing countries are especially relevant in this context, given the unique challenges they face in achieving sustainability. In contrast to developed economies, developing economies are marked by cyclical structural limitations, including high poverty rates, urbanization, ineffective institutional development, and overreliance on traditional energy sources (Rifai 2021). In this respect, sustainable development must be regarded as a slow process with an emphasis on improving the quality of life, which, in turn, will facilitate environmental conservation and ensure long-term economic growth. The lack of specific policies designed to significantly transform livelihoods can render sustainability efforts ineffective and possibly exacerbate inequality (Rifai 2021). Moreover, developing states need substantial international support to implement sustainable changes, especially in the form of grant-based public finance, technology transfer, and capacity development. According to the principle of equity enshrined in the United Nations Framework Convention on Climate Change and the Paris Agreement, developed countries have a duty to support developing economies because they previously benefited from an unequal share of the global CO2 budget (Nesadurai 2025). Along these lines, emerging economies are a sensitive area for observing trends in progress, sustainability, and the success of accompanying policy remedies.

Table 1 presents the average values of carbon dioxide (CO2) emissions, renewable energy consumption (REC), and gross domestic product (GDP) at the country level for the sampled developing economies. The table reveals strong cross-country heterogeneity in economic performance, energy structure, and environmental pressure. Countries with relatively high CO2 emissions and lower shares of RE include China, South Africa, and Iran, which exhibit intensive growth patterns. In contrast, several low-income economies, including Ethiopia, Burundi, and the Democratic Republic of Congo, show high shares of RE but low income and emissions. On the other hand, high incomes and low consumption of RE are found in some resource-endowed and small island economies. This broad cross-country difference highlights the heterogeneity of developing economies. It justifies the use of panel-based empirical methods to analyze the relationship between RE and ECOSUS in a heterogeneous development environment.

Table 1. Sampled countries

Country	CO2	REC	GDP	Country	CO2	REC	GDP
Afghanistan	0.202914	24.73333	456.0536	**Lesotho**	0.27729	47.6875	961.6296
Algeria	3.542351	0.258333	4364.238	**Liberia**	0.188091	90.72917	642.3587
Angola	0.913997	56.75833	3097.46	**Madagascar**	0.110011	84.25417	449.8831
Azerbaijan	3.540425	2.458333	4350.954	**Malawi**	0.289793	78.17917	492.6134
Bangladesh	0.450443	39.37083	1107.601	**Maldives**	3.035875	1.533333	8986.302
Belize	0.663912	31.55	5998.258	**Mali**	0.169496	79.40417	821.734
Benin	0.4674	53.84583	993.6635	**Marshall Islands**	0.002072	14.3625	3887.038
Bhutan	1.402564	85.4125	2450.393	**Mauritania**	0.699828	32	1486.116
Bolivia	1.492572	19.29167	2612.898	**Mexico**	4.019922	10.42083	9721.044
Botswana	2.550601	29.725	6057.559	**Federated States of Micronesia**	0.001816	1.583333	2860.624
Brazil	2.238056	45.45417	8305.042	**Moldova**	2.932809	15.4875	2510.628
Burkina Faso	0.164607	78.93333	589.6281	**Mongolia**	5.719654	4.025	3070.76
Burundi	0.044033	90.9	259.5627	**Morocco**	1.636787	13.55	2808.287
Cabo Verde	1.304607	23.44583	3149.374	**Mozambique**	0.201969	84.8375	501.5768
Cambodia	0.506009	66.42917	1322.359	**Myanmar**	0.354621	74.03333	884.625
Cameroon	0.378769	80.8	1337.352	**Namibia**	1.334924	31.9375	3989.168
China	6.585943	16.25	6720.212	**Nepal**	0.276731	83.95833	794.7372
Colombia	1.622911	30.275	5454.074	**Nicaragua**	0.824579	52.5625	1840.441
Comoros	0.267873	62.1	1294.714	**Niger**	0.086982	82.47083	462.7254
Democratic Republic of Congo	0.043904	96.62083	423.6441	**Nigeria**	0.632341	83.14167	2156.161
Republic of the Congo	1.150435	65.05	2090.125	**Pakistan**	0.820391	46.25	1330.228
Cote d'Ivoire	0.4023	68.28333	1724.586	**Palau**	90.55725	0.291667	14170.53
Cuba	2.307185	23.64167	6527.68	**Papua New Guinea**	0.632227	56.95833	2191.717
Djibouti	0.828924	29.6625	2368.949	**Paraguay**	0.967084	63.80833	5237.84
Dominica	0.991189	9.820833	8008.604	**Peru**	1.49674	32.9	5225.264
Dominican Republic	2.283674	16.9875	6106.178	**Philippines**	1.024644	31.06667	2626.511
Ecuador	2.304419	15.80833	5250.651	**Rwanda**	0.095439	86.425	635.9757

Table 1. Sampled countries (Cont'd)

Country	CO2	REC	GDP	Country	CO2	REC	GDP
El Salvador	1.157907	27.96667	3595.238	**Sao Tome and Principe**	0.61894	44.39583	1232.16
Equatorial Guinea	4.380138	11.2875	8506.63	**Senegal**	0.580959	41.4875	1205.833
Eritrea	0.218213	78.77083	771.7597	**Sierra Leone**	0.137547	80.49583	935.3016
Eswatini	0.89765	65.87083	3124.504	**Solomon Islands**	0.551657	48.49583	1896.565
Ethiopia	0.106006	92.65833	499.1276	**Federal Republic of Somalia**	0.062065	94.075	368.2949
Fiji	1.662677	34.79583	4653.622	**South Africa**	8.191039	9.7875	5717.675
Gabon	3.435027	84.67083	6869.252	**Sudan**	0.429413	66.01667	1211.245
Gambia, The	0.206507	54.7375	659.8951	**Suriname**	3.605294	19.16667	7831.645
Ghana	0.492704	51.49167	1533.666	**Syrian Arab Republic**	2.183786	1.575	1100.208
Grenada	0.9735	10.53333	8187.995	**Tajikistan**	0.602452	52.11667	858.0671
Guatemala	0.946658	64.5125	3698.158	**Tanzania**	0.20327	86.25833	840.6431
Guinea	0.251344	76.60833	759.5962	**Thailand**	3.608401	21.625	5174.32
Guinea-Bissau	0.186859	88.0625	643.0869	**Timor-Leste**	0.448842	28.70833	1251.216
Guyana	2.785382	25.9625	6557.172	**Togo**	0.261456	76.14583	717.5877
Haiti	0.26733	78.68333	1347.321	**Tonga**	1.275562	1.920833	4116.632
Honduras	1.015427	49.74583	2162.613	**Tunisia**	2.440734	13.24583	3689.928
India	1.459017	38.20417	1378.776	**Turkmenistan**	10.94289	0.095833	4655.01
Indonesia	1.895874	32.6	2903.816	**Uganda**	0.121375	93.0875	765.4542
Iran, Islamic Re	7.330532	0.908333	4944.194	**Uzbekistan**	4.361129	1.183333	2364.32
Iraq	3.841449	1.066667	4066.972	**Vanuatu**	0.630141	40.26667	2782.358
Jamaica	3.17791	9.091667	5502.404	**Venezuela**	5.233804	17.75	3401.512
Jordan	2.761702	4.629167	4085.868	**Viet Nam**	2.010406	36.29583	2303.628
Kenya	0.31914	73.75417	1412.806	**Yemen**	0.698352	1.6875	1766.274
Kiribati	0.546777	47.6875	1569.007	**Zambia**	0.318726	86.85833	1132.598
Kyrgyz Republic	1.378853	26.875	997.9345	**Zimbabwe**	0.851741	79.5625	1284.257
Lao PDR	1.228155	62.91667	1769.389	**Total**	2.37371	44.23119	3000.846

In this study, all the concerned variables are sourced from reliable secondary databases. Data on REC, ECOSUS, and other macroeconomic indicators are obtained from the World Bank's World Development Indicators (WDI) database.[1] In contrast, data on green finance are collected from the Our World in Data database.[2] These data sources are widely used in sustainability and energy economics research, ensuring consistency and comparability across countries and over time. The data description is presented in Table 2.

In this study, eco-economic sustainability (ECOSUS) is conceptualized as a theoretical umbrella construct that captures an economy's ability to pursue economic development while limiting environmental degradation. Accordingly, ECOSUS is not constructed as a single composite index in the empirical analysis. Instead, it is operationalized through two complementary dimensions: GDP per capita represents the economic dimension, while CO_2 emissions represent the environmental dimension. This approach allows the study to separately identify whether renewable energy consumption contributes to economic development and environmental protection, rather than imposing a single aggregate measure that may obscure potentially different effects across the two dimensions. Therefore, the empirical models estimate the economic and environmental dimensions of ECOSUS separately, and the overall implications for eco-economic sustainability are interpreted based on the combined evidence from these two outcomes.

Table 2. Data description

Variable	Abbreviation	Measure	Description from data sources
Economic growth	GDP	GDP per capita (constant 2015 US$)	Gross domestic product per capita, adjusted for inflation using 2015 as the base year, represents average economic output per person.
Environmental sustainability	CO_2	CO_2 emissions per capita (tCO_2e), excluding LULUCF	Annual carbon dioxide emissions from energy, agriculture, waste, and industrial activities, excluding land-use change and forestry, expressed per capita.
Renewable energy consumption	REC	% of total final energy consumption	Share of renewable energy sources in total final energy consumption.
Foreign direct investment	FDI	Net (current US$, BoP)	Net foreign direct investment refers to cross-border investments with managerial control or significant influence (at least 10% ownership).
Green finance	GFI	Millions of constant 2022 US$	International financial flows to developing countries supporting renewable energy production and clean energy research and development.
Industrialization	IND	% of GDP	Value added from industrial activities, including manufacturing, mining, construction, and utilities, expressed as a share of GDP.
Trade openness	TRD	% of GDP	Total exports and imports of goods and services as a percentage of GDP.
Urbanization	URB	% of total population	Proportion of the population residing in urban areas, based on national definitions and UN population data.

GDP per capita is used to represent the economic dimension of ECOSUS because it captures an economy's level of development and income-generating capacity. Although GDP per capita does not measure economic sustainability in isolation, it provides an indicator of the

[1] World Bank Database (2025) *https://data.worldbank.org/*
[2] Our World (2025) *https://ourworldindata.org/*

economic development component of eco-economic sustainability when considered alongside environmental performance. CO_2 emissions are used to represent the environmental dimension because they capture the environmental pressure associated with economic and energy-related activities. Examining these two dimensions jointly enables the study to assess whether renewable energy consumption can contribute to economic development while reducing environmental degradation.

3.2. Model specification

This research paper has identified two econometric models that can help understand the immediate influence of RE use on economic sustainability and the moderating impact of financial support. The former model represents the direct relationship, whereas the latter uses interaction terms to capture moderating effects. ECOSUS is the central theoretical construct of the study and is examined empirically using two outcome variables representing its economic and environmental dimensions: GDP per capita and CO_2 emissions.

The economic dimension of eco-economic sustainability is captured in this study using GDP per capita, as it measures an economy's economic development and indicates its capacity to generate income and improve living standards. GDP per capita is not a measure of sustainability per se. Still, it is a necessary metric for assessing the sustainability of economic development, which can be complemented by an environmental indicator such as CO_2 emissions. Therefore, in this study, the economic aspect of eco-economic sustainability is expressed in terms of GDP per capita and the environmental aspect in terms of CO_2 emissions (Bigliardi, 2021).

The standard diagnostic tests before estimation were done to determine the right panel estimation technique. The Breusch-Pagan Lagrange Multiplier test and the Hausman test were used to inform the choice between the fixed-effects and random-effects models. According to these diagnostics, fixed-effects and random-effects estimators were used, respectively. The two-step generalized method of moments (GMM) estimator was also used to enhance robustness and help address potential endogeneity. This method will increase the reliability and consistency of the approximate results.

The econometric models are specified in Equations (1) and (2).

Direct effect:

$$\text{ECOSUS}_{it} = \alpha + \beta_1 REC_{it} + \beta_2 IND_{it} + \beta_3 TRD_{it} + \beta_4 URB_{it} + \varepsilon_{it} \quad (1)$$

Moderating effect

$$\text{ECOSUS}_{it} = \alpha + \beta_1 REC_{it} + \beta_2 FDI/GFI_{it} + \beta_3 REC * FDI/GFI_{it} + \beta_4 IND_{it} + \beta_5 TRD_{it} + \beta_6 URB_{it} + \varepsilon_{it} \quad (2)$$

Equation (1) examines the direct impact of renewable energy consumption (REC) on eco-economic sustainability (ECOSUS), while controlling for industrialization (IND), trade openness (TRD), and urbanization (URB). The error term is denoted by ε_{it}.

Equation (2) extends the baseline model by incorporating financial assistance variables, namely foreign direct investment (FDI) and green finance (GFI), along with their interaction terms with REC ($REC \times FDI/GFI$). This specification allows for an assessment of whether financial assistance strengthens or weakens the impact of renewable energy consumption on ECOSUS. In this study, only selected variables are transformed into their natural logarithmic form. Specifically, carbon dioxide emissions (CO_2), gross domestic product (GDP), foreign direct investment (FDI),

and green finance (GFI) are expressed in logarithms. At the same time, REC and the control variables are retained in their original levels. The logarithmic transformation is applied to reduce skewness, address heteroscedasticity, and limit the influence of extreme values, which are common in macro-panel data.

4. Results and discussion

4.1. Descriptive statistics

Table 3 presents the descriptive statistics for the study variables, based on 2,568 observations from developing countries over the period 2000–2023. CO_2 emissions have a mean value of −0.303 and a standard deviation of 1.562, with values ranging from −0.303 to 5.313. The relatively large standard deviation indicates considerable dispersion in CO_2 emissions across the sample, reflecting substantial differences in environmental performance among developing countries. The logged GDP per capita has a mean of 7.617 and a standard deviation of 0.921, with values ranging from 5.451 to 10.048, indicating meaningful variation in income levels and economic development across countries. REC has a mean value of 44.23% of total final energy consumption and a standard deviation of 30.68, with values ranging from 0 to 98.3%. This wide range indicates substantial cross-country variation in the share of renewable energy in total final energy consumption. The financial assistance variables also exhibit considerable variation across countries. The logarithmically transformed FDI has a mean of 26.15 and ranges from 0 to 26.73, indicating substantial differences in foreign investment flows across the sample. Green finance has a mean of 11.09 and a standard deviation of 7.52, with a maximum value of 22.30, suggesting considerable variation in the availability of environmentally oriented financial resources. Overall, the descriptive statistics indicate substantial heterogeneity among the sampled developing countries in environmental performance, economic development, renewable energy consumption, and financial assistance.

Table 3. Descriptive Statistics

Variable	Obs.	Mean	Std. Dev.	Min	Max
CO2	2568	-.303	1.562	-6.334	5.313
GDP	2568	7.617	.921	5.451	10.048
REC	2568	44.231	30.68	0	98.3
FDI	2568	26.146	.524	0	26.73
GFI	2568	11.089	7.515	0	22.299
IND	2568	26.555	12.358	2.774	84.796
TRD	2568	75.036	41.071	0	347.72
URB	2568	46.399	19.308	8.044	92.682

4.2. Correlation

Table 4 reports the pairwise correlation matrix among the study variables. CO_2 emissions are positively correlated with GDP per capita ($r = 0.682$), indicating that higher-income countries in the sample tend to have higher CO_2 emissions at the bivariate level. In contrast, REC is negatively correlated with CO_2 emissions ($r = -0.585$), suggesting an inverse association between renewable energy consumption and CO_2 emissions. REC also exhibits a negative correlation with GDP per capita ($r = -0.704$), indicating that countries with higher shares of renewable energy consumption tend to have lower income levels in the sample. This association may reflect differences in energy structures, levels of development, and the composition of renewable energy sources across developing countries.

Regarding the financial variables, FDI shows weak negative correlations with both CO_2 emissions ($r = -0.050$) and GDP per capita ($r = -0.046$). At the same time, green finance exhibits a weak positive correlation with REC ($r = 0.041$) and no statistically meaningful direct correlation with CO_2 emissions. These pairwise relationships provide preliminary evidence of associations among the variables but should not be interpreted as causal relationships. The VIF values range from 1.01 to 1.31, indicating that the explanatory variables do not exhibit serious multicollinearity concerns. However, VIF is used specifically to assess multicollinearity and does not by itself establish the overall suitability or adequacy of the regression models. The subsequent regression analysis therefore provides a more comprehensive assessment of the relationships after controlling for the relevant covariates and country-specific effects.

Table 4. Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	VIF
(1) CO2	1.000								
(2) GDP	0.682***	1.000							
(3) REC	-0.585***	-0.704***	1.000						1.31
(4) FDI	-0.050**	-0.046**	0.034*	1.000					1.01
(5) GFI	0.023	-0.018	0.041**	-0.039**	1.000				1.03
(6) IND	0.415***	0.288***	-0.179***	-0.045**	0.011	1.000			1.07
(7) TRD	0.086***	0.150***	-0.187***	0.025	-0.148***	0.052***	1.000		1.06
(8) URB	0.502***	0.602***	-0.452***	-0.019	0.028	0.246***	0.043**	1.00	1.31

4.3. Regression results and discussion

Tables 5 and 6 present the regression results for both dependent variables. Table 5 covers environmental sustainability, and Table 6 covers economic growth. The Hausman and Breusch Pagan LM tests guide the choice of estimation techniques. For the CO_2 emissions models, the Hausman test is highly significant ($\chi^2 = 43.834$, $p < 0.01$), indicating systematic differences between fixed-effects and random-effects estimators. This supports the use of the fixed effects model, suggesting that unobserved country-specific characteristics are correlated with the regressors. Moreover, the Breusch Pagan LM test is also significant, confirming the presence of panel effects and justifying panel estimation over pooled OLS. In contrast, for the GDP models, the Hausman test is not statistically significant ($\chi^2 = 3.986$), implying that the random-effects estimator is consistent and efficient. The significant Breusch-Pagan LM statistic further supports the use of a random-effects framework for economic growth.

In the direct-effects model, REC has a significant negative effect on CO_2 emissions, indicating an improvement in the environmental dimension of eco-economic sustainability ($\beta = -0.031$, $p< 0.01$). In addition to statistical significance, the coefficient indicates that for every 1-unit increase in REC, CO_2 emissions decrease by 0.031 units, holding other variables constant. As the proportion of renewable energy in total final energy increases, the size reflects the environmental benefits of increased renewable energy use. The estimated impact is not significant per se, but it can be important when countries continue to increase their REC over time. This result aligns with previous empirical studies demonstrating the important role of REC in reducing CO_2 emissions and ecological pressure (Guo et al. 2023; Raihan and Tuspekova 2022; Usman et al. 2020). It also supports arguments that REC can achieve decarbonization of the economy by reducing CO_2 intensity and improving energy efficiency (Chang et al. 2022; Lee et al. 2023; Sharif et al. 2024). In general, the findings are consistent with the view that REC can be an effective policy tool to reduce emissions in developing nations, where the challenges of doing so are more severe (Abbasi et al. 2022).

Further insights on the REC-environment nexus are gained by analyzing the moderating effect of FDI. REC is negatively and significantly associated with FDI ($\beta = -0.025$, $p < 0.01$). The magnitude of the interaction coefficient indicates that the marginal environmental effect of REC on FDI becomes increasingly negative. In other words, the interaction coefficient indicates an additional 0.025 unit of CO_2 savings per 1-unit increase in FDI for every 1-unit increase in REC, holding other factors constant. Therefore, the moderating effect is economically relevant, as it reflects the fact that the environmental benefits of REC are not priced independently. These benefits can be enhanced by FDI, which can help reduce financial constraints, support the development of larger-scale clean energy projects, and facilitate technology transfer. The results corroborate the findings of Aust et al. (2020) and Gusmão Caiado et al. (2018), who suggest that foreign investment leads to the quicker adoption of clean technologies in capital-constrained economies. Furthermore, the findings are in line with Abbas et al. (2021), who report that FDI has an integrating effect, enhancing energy efficiency and encouraging clean energy use.

Table 5. Fixed-effect estimation (Dependent variable: CO2)

	(1)	(2)	(3)
VARIABLES	**Direct effect**	**Moderating effect**	
REC	-0.031***	0.627***	-0.031***
	(0.0009)	(0.2101)	(0.0009)
FDI		0.283***	
		(0.0909)	
REN*FDI		-0.025***	
		(0.0080)	
GFI			0.003***
			(0.0012)
REN*GFI			-0.0001**
			(0.0000)
IND	0.008***	0.008***	0.008***
	(0.0009)	(0.0009)	(0.0009)
TRD	0.002***	0.002***	0.002***
	(0.0003)	(0.0003)	(0.0003)
URB	0.009***	0.009***	0.009***
	(0.0012)	(0.0012)	(0.0012)
Constant	0.318***	-7.104***	0.291***
	(0.0915)	(2.3810)	(0.0928)
Observations	2,568	2,568	2,568
R-squared	0.488	0.490	0.490
Number of countries	107	107	107
F-Stat	585.8	393.4	392.8
Prob>F	0	0	0
Husman test	43.834***		
Breusch pagan LM test	26784.58***		

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The same moderating pattern also holds for green finance. The results show that the interaction between REC and green finance is negative and statistically significant ($\beta = -0.0001$, $p < 0.05$), implying that increasing the amount of green finance will amplify the emission-reducing effect of REC. The numerical value of the interaction coefficient is not particularly large, but it should be considered relative to the scale of the green finance variable. The negative coefficient suggests that the more RECs there are, the better the average environmental effect of RECs is. This result is in line with the literature claiming that green finance reduces investment risks,

increases the availability of long-term funding, and redirects financial flows towards "green" investment projects that could otherwise be underfunded. Sun et al. (2025) and Zhu et al. (2025) empirically validated the contribution of green finance to environmental sustainability. They demonstrated that green financing is vital to CO_2 emissions reduction, as shown by Sharif et al. (2022). The study thus indicates that green finance could benefit mainstream investment in green environments and also enhance the effectiveness of REC.

Table 6. Random-effects estimation (Dependent variable: GDP)

	(1)	(2)	(3)
VARIABLES	**Direct effect**	**Moderating effect**	
REC	-0.014***	0.717***	-0.013***
	(0.0006)	(0.1637)	(0.0007)
FDI		0.316***	
		(0.0708)	
REN*FDI		-0.028***	
		(0.0063)	
GFI			0.009***
			(0.0009)
REN*GFI			-0.0001***
			(0.0000)
IND	0.013***	0.013***	0.013***
	(0.0007)	(0.0007)	(0.0007)
TRD	-0.001***	-0.001***	-0.001***
	(0.0002)	(0.0002)	(0.0002)
URB	0.018***	0.018***	0.017***
	(0.0009)	(0.0009)	(0.0009)
Constant	7.143***	-1.117	7.090***
	(0.0877)	(1.8551)	(0.0879)
Observations	2,568	2,568	2,568
R-squared	0.451	0.455	0.473
Number of countries	107	107	107
Wald Chi2	2182	2217	2361
Prob>chi2	0	0	0
Husman test	3.986		
Breusch pagan LM test	24837.63***		

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

In contrast, REC has a significant negative association with GDP per capita, indicating a short-term adverse effect on the economic dimension ($\beta = -0.014$, $p < 0.01$). The coefficient indicates a 0.014-unit decrease in GDP for each 1-unit increase in REC (holding everything else constant). While the magnitude is not very large, the negative association is economically significant, indicating that a higher proportion of renewable energy could entail short-term adjustment costs in developing economies. These costs can result from high start-up costs, infrastructure limitations, technological constraints, and the reallocation of resources from existing energy systems. This discovery is consistent with research that has focused on the early years of the energy transition and identified some of the adjustment frictions faced (Abdi et al. 2025; Hwang and Sánchez Díez 2024). Meanwhile, the current literature indicates that REC can foster long-term economic growth when paired with appropriate financial and institutional arrangements (Kasperowicz et al. 2020; Wang et al. 2022a). Hence, the relatively small coefficient should not be taken to mean that renewable energy is a bad ingredient in economic growth, as it reflects transition costs during the study period.

FDI is known to be a growth-enhancing factor, as it brings capital, technology transfer, and productivity spillovers (Dankyi et al. 2022). In the present study, however, the interaction between REC and FDI is negative and statistically significant ($\beta = -0.028$, $p < 0.01$). The signs suggest that the negative relationship between REC and GDP is strengthened with the growth of FDI. Specifically, given an additional FDI unit, the estimated marginal impact of a unit of REC on GDP is 0.028 units lower, controlling for all other variables. The findings indicate that the immediate growth advantages of FDI do not apply uniformly with the expansion of renewable energy. Foreign investment might also go to capital-intensive renewable energy investments with limited short-term job creation or productivity spillover benefits, and limited absorptive capacity and adjustment costs may limit the initial economic gains. The findings align with the findings of transition-oriented studies that highlight the uneven distribution of growth effects of renewable energy investments, and disagree with the literature that suggests that the positive growth benefits of renewable energy investments can be amplified when the investments are efficiently allocated, as suggested by Appiah-Otto et al. (2023) and Raihan et al. (2025).

Green finance is usually linked to energy efficiency and long-term economic performance through the allocation of financial resources to green activities (Huo et al. 2022; Wen et al. 2025). However, the relationship between REC and green finance is adverse and statistically significant ($\beta = -0.0001$, $p < 0.01$). The numerical value of the coefficient is small. Still, it suggests that increased availability of green finance is associated with a more negative short-term marginal effect of REC on GDP. This could be because the first investments in green financial instruments are aimed at investments that require high levels of capital expenditure and are designed to improve the environment, thereby generating economic returns over a longer term. Because of this, it is necessary to consider the short-term economic impact alongside the environmental benefits of the transition, rather than as a sign that green finance is not working. This is in line with the finding that financial instruments for green technologies can create a growth dividend not immediately (Phung Thanh 2022), but in the long term.

These results do not imply that REC produces a uniformly positive or negative effect on eco-economic sustainability. Rather, REC generates differentiated effects across its two dimensions. The negative coefficient for CO_2 emissions indicates an environmental benefit, whereas the negative coefficient for GDP per capita indicates a short-term economic cost. The combined evidence therefore suggests a potential sustainability trade-off during the renewable energy transition in developing economies. Moreover, the interaction coefficients indicate that financial conditions significantly influence these relationships: strengthening FDI and green finance flows both enhance the emissions-reducing effect of REC and, in turn, are associated with a more pronounced negative short-term relationship between REC and GDP. The results indicate that the switch to renewable energy could come at a short-term cost to the economy, while providing environmental benefits. Therefore, financial support needs to be complemented by policies that enhance the technological capacity, infrastructure, productivity, and absorptive capacity of developing economies to lessen the short-term costs of transition while maximizing the longer-term economic and environmental gains.

The empirical findings provide differentiated support for the proposed hypotheses across the economic and environmental dimensions of eco-economic sustainability. The negative and statistically significant coefficient of REC in the CO_2 model supports the hypothesis that REC improves the environmental dimension of ECOSUS. However, the negative and statistically significant coefficient of REC in the GDP model contradicts the hypothesized positive effect on

economic growth; therefore, the corresponding economic-growth hypothesis is rejected. The interaction results further demonstrate that FDI strengthens the environmental benefits of REC, as reflected by the negative and significant REC × FDI coefficient in the CO_2 model, supporting the corresponding moderation hypothesis. In contrast, the negative and significant REC × FDI coefficient in the GDP model indicates that FDI strengthens the negative short-term association between REC and GDP, leading to rejection of the hypothesis predicting a positive moderating effect on economic growth. A similar pattern is observed for green finance. The negative REC × GFI coefficient in the CO_2 model supports the hypothesis that green finance strengthens REC's emissions-reducing effect. In contrast, the negative REC × GFI coefficient in the GDP model does not support the expected positive moderation of the REC-growth relationship. Overall, the hypotheses receive mixed support, highlighting that financial support enhances the environmental effectiveness of REC but does not necessarily eliminate its short-term economic costs.

Table 7. Two-Step System GMM (Dependent variable: CO2)

	(1)	(2)	(3)
VARIABLES	**Direct effect**	**Moderating effect**	
CO2 (-1)	0.869***	0.751***	0.802***
	(0.0421)	(0.0841)	(0.0380)
REC	-0.003***	3.547*	-0.006***
	(0.0010)	(1.8802)	(0.0015)
FDI		1.537*	
		(0.8205)	
REN*FDI		-0.136*	
		(0.0719)	
GFI			0.003**
			(0.0013)
REN*GFI			-0.0001**
			(0.0000)
IND	0.005***	0.011***	0.006***
	(0.0015)	(0.0029)	(0.0014)
TRD	-0.000	-0.000	-0.000
	(0.0001)	(0.0005)	(0.0002)
URB	0.002*	0.002	0.002**
	(0.0010)	(0.0020)	(0.0010)
Constant	-0.106*	-40.397*	-0.052
	(0.0583)	(21.5214)	(0.0642)
AR (1)	-6.05	-5.31	-6.26
Prob.	0.000	0.000	0.000
AR (2)	-0.68	-0.33	-0.71
Prob.	0.49	0.75	0.48
Hansen test	26.50	19.78	51.26
Prob.	0.23	0.54	0.21
Number of countries	107	107	107
Number of instruments	28	29	52
F-Stat	26058	1721	4524
Prob>F	0	0	0

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

4.4. Generalized Method of Moments (GMM)

Tables 7 and 8 present the results from GMM. Table 7 covers environmental sustainability, and Table 8 covers economic growth. The two-step system GMM findings affirm the strength of the baseline panel estimates after correcting for endogeneity, dynamic persistence, and unobserved

heterogeneity. In both CO2 emissions and GDP, the lagged dependent variables are positive and highly significant, indicating high persistence and thus justifying the dynamic specification. To establish the validity of the models, the diagnostic tests show that AR(1) is significant and AR(2) is non-significant in all the models. The p-value of the Hansen test exceeds the conventional significance level, indicating that the instruments are valid.

Table 8. Two-Step System GMM (Dependent variable: GDP)

	(1)	(2)	(3)
VARIABLES	**Direct effect**	**Moderating effect**	
GDP (-1)	0.640***	1.010***	0.879***
	(0.0762)	(0.0057)	(0.0088)
REC	-0.028***	0.384***	-0.002***
	(0.0047)	(0.0566)	(0.0003)
FDI		0.164***	
		(0.0246)	
REN*FDI		-0.015***	
		(0.0022)	
GFI			0.008***
			(0.0004)
REN*GFI			-0.0001***
			(0.0000)
IND	0.001	0.003***	0.003***
	(0.0036)	(0.0002)	(0.0001)
TRD	0.002**	0.001***	0.003***
	(0.0009)	(0.0001)	(0.0001)
URB	-0.011*	-0.003***	-0.004***
	(0.0059)	(0.0002)	(0.0003)
Constant	4.288***	-4.342***	0.904***
	(0.5400)	(0.6243)	(0.0780)
AR (1)	-3.08	-3.69	-3.99
Prob.	0.002	0.000	0.000
AR (2)	0.76	-1.63	-1.45
Prob.	0.45	0.102	0.15
Hansen test	25.11	102.64	104.01
Prob.	0.16	0.12	0.13
Number of countries	107	107	107
Number of instruments	25	95	97
F-Stat	3940	2.100e+07	3.480e+06
Prob>F	0	0	0

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

In the case of CO2 emissions, the REC consistently reduces emissions; this underscores its importance in enhancing environmental sustainability in developing nations. This impact is further reinforced by the fact that financial support amplifies it: FDI and green finance increase the emissions-reducing potential of RE, and the complementary nature of these financial mechanisms in facilitating clean energy transitions should be noted. By contrast, the REC shows a negative short-run impact on the growth of an economy; this is due to adjustment costs and structural bottlenecks that are normally experienced within developing economies during energy transitions. The engagement with financial support is adverse, indicating that although FDI and green finance enhance environmental benefits, they do not mitigate growth-related issues associated with the immediate introduction of RE. Altogether, the system GMM data is comparable with the baseline data and is more causal. Adopting RE solutions is effective in alleviating environmental pressures

in developing economies, although the economic benefits are limited in the short term. Funding is an important concern for improving environmental performance, and coordinated efforts between energy and financial policies can lead to sustainable economic performance in the long run.

4.5. Marginal Plots

The marginal effect plots in Figure 2 provide further evidence of the moderating roles of FDI and green finance in the relationship between REC and sustainability outcomes. MP (a) shows that the negative effect of REC on CO_2 emissions becomes substantially stronger at higher FDI levels, confirming that FDI enhances the environmental benefits of renewable energy consumption. In contrast, MP (b) indicates that the relationship between REC and GDP varies with FDI levels, with the negative association becoming more pronounced at higher FDI levels, suggesting that FDI may intensify the short-term economic costs associated with the renewable energy transition. Similarly, MP (c) demonstrates that CO_2 emissions decline as REC increases under both low and high levels of green finance, with the reduction being stronger at higher green finance levels, indicating that green finance reinforces the emissions-reducing effect of REC. Finally, MP (d) shows a declining relationship between REC and GDP at both levels of green finance, with the lines converging at higher REC levels, suggesting that green finance does not eliminate the short-term negative association between renewable energy consumption and economic growth. Overall, the marginal plots confirm that financial support plays an important role in shaping REC's sustainability outcomes, strengthening its environmental benefits while not fully offsetting its short-term economic costs.

5. Conclusion

This paper investigates the impact of renewable energy consumption (REC) on the economic and environmental dimensions of eco-economic sustainability in developing countries, specifically the moderating effects of foreign direct investment (FDI) and green finance. The study utilizes a large panel of 107 developing countries across 2000–2023, employing fixed-effects, random-effects, and two-step system GMM estimations to provide robust evidence on the relationship between REC and the economic and environmental aspects of sustainability. The findings indicate that REC improves the environmental dimension of eco-economic sustainability by reducing CO_2 emissions, while its negative association with GDP per capita suggests short-term economic adjustment costs. Therefore, the overall implications for eco-economic sustainability depend on developing economies' ability to manage these economic costs while preserving the environmental gains associated with the renewable energy transition.

A key finding of the study concerns the moderating role of financial assistance. The interaction effects demonstrate that FDI strengthens the emissions-reducing effect of REC, indicating that foreign capital can facilitate the deployment of cleaner technologies, renewable energy infrastructure, and associated technological capabilities. However, the negative REC × FDI coefficient in the GDP model indicates that FDI also strengthens the negative short-run association between REC and economic growth. A similar pattern is observed for green finance. While the negative REC × GFI coefficient in the CO_2 model indicates that green finance reinforces the environmental benefits of REC, its negative interaction with REC in the GDP model suggests that green finance does not immediately offset the economic adjustment costs associated with the energy transition. These findings indicate that financial assistance can improve the environmental effectiveness of renewable energy while simultaneously being associated with greater short-term economic costs.

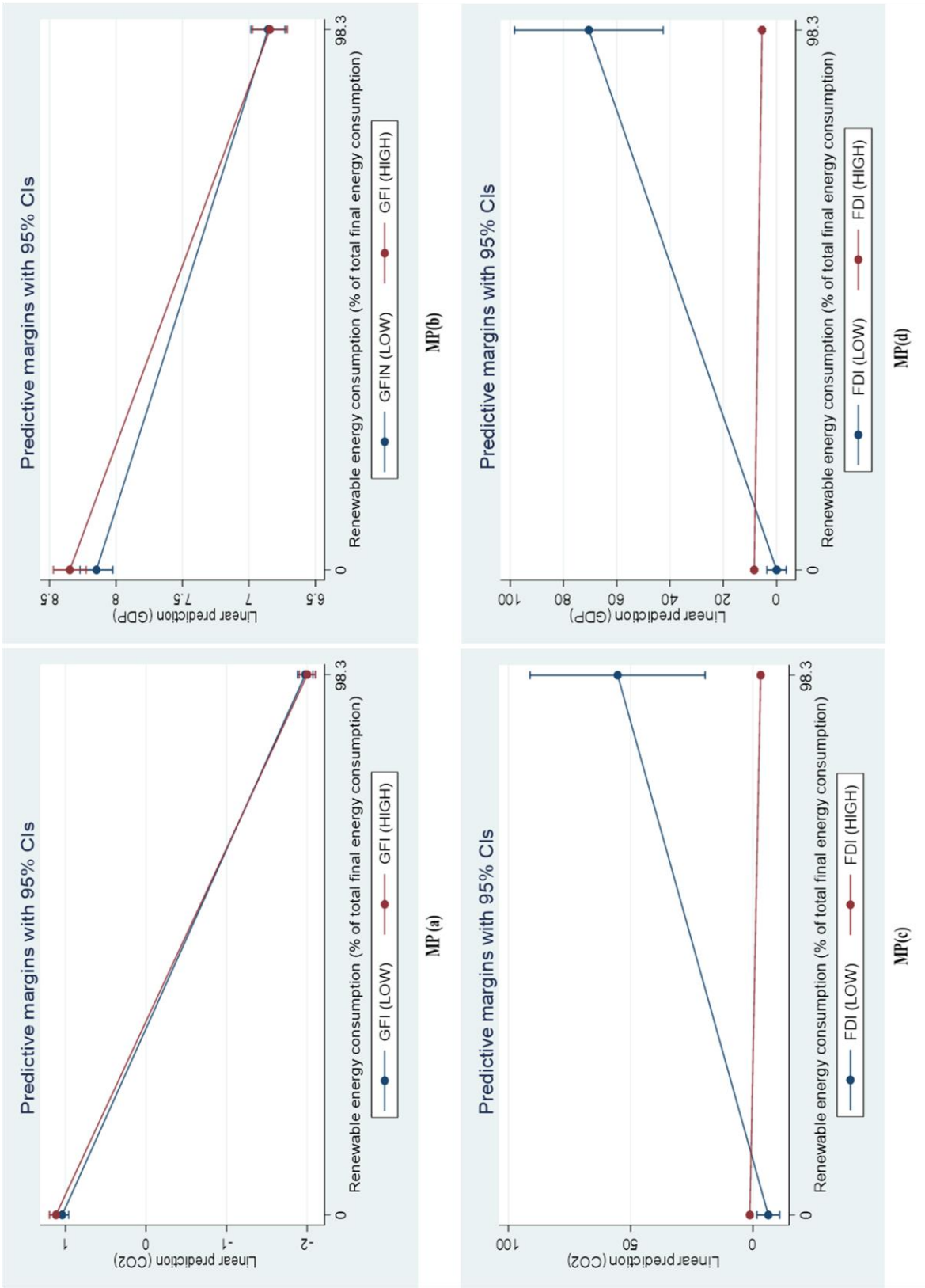


Figure 2. Marginal plots

This apparent trade-off can be explained by the different timing of environmental and economic effects. Financial assistance can accelerate renewable energy deployment and generate relatively immediate environmental gains through the substitution of fossil-based energy and adoption of cleaner technologies. In contrast, the economic returns from such investments may take longer to materialize because renewable energy projects require substantial upfront capital, infrastructure development, technological adaptation, and institutional capacity. In developing economies, these transition costs may temporarily constrain productive resources and economic output, particularly where domestic infrastructure and absorptive capacity remain limited. Therefore, the negative interaction effects for GDP should be interpreted as evidence of short-run adjustment costs rather than a rejection of the potential long-run economic benefits of renewable energy and financial support.

In policy terms, developing countries should therefore implement renewable energy policies in conjunction with measures to make finance available, foster technological change, build energy infrastructure, and build absorptive capacity. Financial support should be targeted to projects with potential to provide environmental benefits and productive economic spillovers. This holistic perspective can be used to minimize the immediate economic burden of the transition to renewables and enhance their role in sustainable development in the medium and long term.

This analysis could be extended in several ways in the future. It is important to note that, given the large economies of developing nations, future studies should examine whether the impact of REC and financial assistance varies by income group, geographical region, institutional setting, and level of financial development. Second, researchers could examine the nonlinear, threshold, and asymmetric effects of REC to see whether the economic and environmental impacts of the resource vary beyond certain thresholds of renewable energy deployment or financial assistance. Third, future studies might include additional measures of institutional quality, technological innovation, energy infrastructure, and financial development to understand better the conditions that could enable a more balanced path toward a sustainability transition. Finally, more disaggregated indicators of renewable energy consumption (e.g., solar and wind consumption, and various types of green finance) may provide more information on which renewable energy and financial products are best suited to reconcile economic development and environmental protection.

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