# Mitigating CO2 Emissions through Economic Growth, Green Finance, and Renewable Energy: Evidence from an ARDL Analysis

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## Abstract

This study examines the intricate long-term relationships between global $CO_2$ emissions and three pivotal factors: global gross domestic product (GDP), green finance flows in developing economies, and global renewable energy consumption. The study spans data from 2000 to 2021, addressing critical questions on sustainability and economic growth amidst growing environmental concerns. This investigation is timely as it aligns with international efforts to mitigate climate change and transition towards greener economies. The primary objective of this research is to analyse the interplay between economic growth, financial mechanisms, and renewable energy in influencing global $CO_2$ emissions. It aims to provide empirical insights into their dynamics and offer policy recommendations for sustainable development. Using the Autoregressive Distributed Lag (ARDL) model, the study investigates long-run and short-run relationships among these variables. The approach ensures robust statistical modelling of the time-series data while considering the complexities of cross-country variations. The findings reveal a significant positive correlation between global GDP and $CO_2$ emissions, indicating that a 1% increase in global GDP leads to a 0.48% rise in emissions. Conversely, renewable energy consumption exhibits a substantial negative relationship, where a 1% increase reduces $CO_2$ emissions by 0.77%. Notably, green finance in developing countries shows a positive but statistically insignificant impact on emissions, highlighting gaps in its current implementation and effectiveness. This study contributes to the Environmental Kuznets Curve (EKC) hypothesis by illustrating that the current global economy has not reached a maturity level that fosters emission reductions alongside economic growth. It underscores the role of renewable energy and green finance in shaping sustainable economic paradigms. The research highlights policy imperatives, urging governments to: (1) scale up investments in renewable energy to combat climate change effectively; (2) enhance the efficiency and governance of green finance mechanisms in developing economies to ensure impactful emission reductions; and (3) align economic growth strategies with environmental sustainability goals.

## Key words

CO2 emissions, renewable energy, green finance, economic growth, sustainability.

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## Introduction

The development and worsening of the climate change problem have called for enhanced attention and demand from policymakers, researchers and industries to provide methods of minimising carbon production. Among the suggested measures, green finance, the consumption of renewable energy, and adapting sustainable economic development are some of the significant features that have become important in the process of countering adverse climate change impacts at the global level. Green finance, meaning financial flows towards green economy projects which are financed through the efficient management of financial resources, has been advocated as a key approach towards promoting the development of renewable energy conservation and other sustainable initiatives (Wu, 2023). As a result, green finance provides funds toward clean energy projects that can greatly minimise the utilisation of fossil products, which are among the key sources of global CO2 emission (Ali et al., 2023). However, the efficacy and indeed applicability of green finance, particularly, but not exclusively, in developing nations, is still an open question, though some research has claimed that its current volume is insufficient to meaningfully move the needle on emissions reductions (Sun et al., 2023).

The use of renewable energy has been considered one of the potential options for $CO_2$ emission reduction. Clean energy investments such as the solar industry, wind industry, and hydropower have been shown to cause a decline in carbon emissions as they enhance the economy (Jin et al., 2023). For instance, renewable energy assists not only in shaping the sustainable generation of energy but also enables countries to meet their carbon neutrality goals by replacing fossil energy, which is the main source of emissions of greenhouse gases (Cooke, 2023). In addition, there are indications from other studies that renewable energy has an impact on employment generation, technological development, and sustainable economic growth and development for the long haul (Ali et al., 2023). Nevertheless, the utilisation of renewable energy has a number of issues, such as high initial investment costs and scarcity of green funding in emerging markets (Xu et al., 2023).

Economic development previously tied to emission increase based on industrialisation and the use of energy, has an ambiguous interaction with sustainable environment. Environmental Kuznets Curve (EKC) hypothesis postulates that economic progress first provokes pollution as the economy tries to industrialize; then pollution declines as incomes increase and use cleaner technologies (Khan et al., 2021). Although this hypothesis has been proved beyond doubt in some developed countries, particularly those which belong to the Organisation for Economic Cooperation and Development (OECD), it has remained a subject of debate in developing countries where the higher level of industrialisation results in higher levels of CO2 emission but without a simultaneous transition to cleaner technologies (Jin et al., 2023). Hence, for developing countries to achieve enhanced economic growth, it is necessary for them to tap into green finance and renewable energy, but more importantly, firm institutional quality that supports environmental sustainability and good governance (Xu et al., 2023). Institutional quality and governance have also been recommended as key driving forces for green finance and low carbon emission. The general legal structures of a country accompanied by political stability and the efficiency of the regulatory framework support the growth of green finance. There is evidence that strong institutions are a blessing in terms of enabling the development of renewable energy and clean technologies required to support the change to a low-carbon economy (Xu et al., 2023). However, weak institutions hinder green finance development; resource allocation is not efficient, and emission reduction progress slows down (Ali et al., 2023). However, good governance may also increase the implementation efficiency of environmental policies, improve accountability, and promote joint efforts of civil society and business in countering climate change (Jin et al., 2023).

Previous studies (Xu et al., 2023; Ali et al., 2023; Jin et al., 2023) have reached conflicting conclusions on the impact of green finance on emission reduction, especially in developing countries where green finance is weak or non-existent. According to Sun et al. (2023), green finance has been essential in advancing renewable energy initiatives in China; however, its influence in other developing areas has not been as pronounced. This indicates a necessity for more focused and efficient green finance strategies that can more effectively facilitate the shift toward clean energy. Likewise, Xu et al. (2023) suggest that only when there are robust institutional arrangements can green finance be well deployed to sustainable projects especially for those countries with relatively poor governance.

The use of renewable energy sources has been acknowledged globally as a crucial driver of the reduction of carbon emissions, with studies pointing towards sustainability as the goal to be achieved. For instance, Wu (2023) also shows that international investment in the renewable energy sector has impacted OECD countries by lowering emissions but at the same time assisting economic growth. Similar to Jin et al. (2023), the expansion of renewable energy installation is equally important for industrialised economy countries in their bid to implement the carbon-neutral agenda. However, there are difficulties in integrating renewable energy systems in developing countries, mainly due to restricted financing and technical support (Xu et al., 2023). The management of such barriers will be critical in attaining a sustained decline in global $CO_2$ emissions.

It is therefore clear that the correlation between economic growth and CO2 emissions cannot be generalized without fully understanding the context which they are in developed, developing, or transition economies. According to Khan et al. (2021), economic development increases emissions during the process of industrialization. But things have changed over the recent years with increased uptake of cleaner energies and technologies making this a shift in the longer run. However, these tasks can be realized only through a coordinated drive towards green finance, technology support, and institutional improvement (Khalifa et al., 2024). Thus, this study aims to enrich the existing body of knowledge on how green finance, Renewable energy (RE) and economic growth as the main factors help minimize global CO2 emission and support sustainable development.

The present research aims to fill the identified gap towards addressing the paramount question on how long-term relationship between green finance, renewable energy, and economic growth affects global CO2 emissions. In order to come up with relevant policy implications that may perhaps be utilized towards achieving emission reductions and consequently advancing environmental sustainability, this study employs the ARDL model on data that has been gathered across the quarters from 2000 to 2021. Thus, by stressing on the role of proper green finance flows, renewable energy consumption and institutions, the study support the further practices regarding mitigation of climate change and sustainable development.

## 1. Literature review

### *1.1. Green Finance and CO2 Emissions*

Green finance has become important in the world in its fight against climate change and in the reduction of CO2 emission through the financing of sustainable projects. However, the ability of green finance to cut emissions is still under much discussion and a number of studies has given different results. Some studies presented in Table 1 (Wu, 2023; Sadiq et al., 2023; Xu et al.,2023) make assertive that green finance helps implement change in the energy mix and bring about emission reductions. Some studies (Sun et al., 2023; Ali et al., 2023) indicate that the size and the adoption of green finance to achieve substantial emission cuts in global CO2 emissions may not be sufficient and may remain a role for developing countries.

Green finance can reduce emissions by funding sustainable projects and promoting technological innovation. Sustainability-linked financing like green bonds, loans and sustainability bonds are tools that policies to facilitate the flow of capital toward green activities, including the extent of renewable energy, energy efficiency, and environment-friendly industrial operations (Sadiq et al., 2023). Wu (2023) also discovers that green finance has a significant effect in controlling emissions together with empowering the growth of developed economies such as the OECD countries. Wu (2023) works confirm that within the green finance gradient, a rise by one percent boosts the economic performance by only 0.591 percent, which means the direction of financial flows toward clean technologies allows for environmental and economic benefits to be attained in tandem.

**Table 1.** Summary of Key Studies on Green Finance and CO2 Emissions.

| Author/Year | Methodology | Results | Contributions | Limitations |
|---|---|---|---|---|
| Wu (2023) | GMM, Fixed Effects Model | Green finance reduces CO2 emissions and improves economic performance in OECD countries. | Highlights the role of green finance in fostering sustainable growth in developed economies. | Focuses on OECD countries; limited insights into developing regions. |
| Sadiq et al. (2023) | CS ARDL, Panel Data Analysis | Green finance and eco-innovation significantly reduce CO2 emissions in BRICS countries. | Emphasizes the importance of eco-innovation and green finance in reducing emissions. | Lacks sector-specific analysis. |
| Sun et al. (2023) | NARDL, Time Series Data | Green finance promotes renewable energy in China but has limited impact in other developing regions. | Offers insights into the regional differences in the effectiveness of green finance. | Limited focus on the scalability of green finance in developing countries. |
| Ali et al. (2023) | RALS co-integration and QARDL | Green finance has potential in South Asia but is hindered by weak banking sector development. | Focus on the role of institutional quality and banking sector development in green finance. | Challenges in mobilizing green finance for large-scale projects in developing countries. |
| Xu et al. (2023) | GMM, Quantile Regression | Institutional quality enhances green finance's impact on reducing CO2 emissions in South Asia. | Highlights the critical role of strong institutions in ensuring the effectiveness of green finance. | Lacks analysis of how green finance mechanisms differ across regions. |

Source: Compiled by the authors.

However, green finance cannot work effectively in the development regions, and its efficiency is low. Sun et al. (2023) argue that even though green finance has brought changes in support of renewable energy in countries such as China the same has not had a strong effect in other developing regions. This is relatively due to the scarcity of green finance instruments as well as potential issues with regards to mobilization of vast sustainable finance for sustainable undertakings. For instance, in South Asia Ali et al. (2023) noted that even though green finance had benefits in its ability to cut emissions, its application has been limited by the under development of the banking sector alongside lack of institutional support (Gherbi, 2019). The study finds that in these regions green finance products are still little in the market to create significant differences in reducing the level of CO2 emissions.

In addition, Xu et al. (2023) found that institutional quality is the crucial factor that can influence green finance outcomes. Taking their observations into account, they concluded that nation states with sustainable political and contracting environments and high-quality regulatory mechanisms as well as well-considered policies for green finance will create the right conditions for investment and will help bring emissions reductions to desired levels. On the other hand, the nations with less developed institutions cannot effectively direct the green finance in order to deliver higher negative effects on emission intensity. This shows that there is a requirement of significant policies for promoting green finance so that it should help projects, which have a positive, measurable effect on sustainability.

These difficulties, however, have demonstrated that green finance is a relevant method that helps to promote sustainable initiatives and develop new innovations in clean technologies. The good thing about green finance is that it provides private capital solutions for sectors that hitherto have relied on public funding. For instance, green bonds have emerged as a common financial product through which different levels of government and corporations are able to issue debt securities primarily to fund sustainable initiatives (Jin et al., 2023). These bonds offer credit assurances and give a favourable foothold for investors to fund projects committed to environmental objectives (Ghermi, 2021). Green bonds have been used to finance renewable energy systems, increase energy efficiency in commercial properties and even create novel ways of lowering the level of CO2 emissions.

Besides, it provides funds for implementing innovation and sustainable initiatives of green technologies. According to Sadiq et al. (2023), green finance acts effectively as a driver and enabler of eco-innovation, the lack of which slows down the reduction in the carbon sensitivity of industrial production. Carbon capture and storage, improved manufacturing technologies and practices, and intelligent electricity distribution services are some of the technologies that green finance helps to advance. All these changes not only entail emission cuts, but it is also evident that sustainability is a key component of sustainable economic development.

But of course, green finance is not without challenges especially in the developing world as shall be discussed below. The perceived cost of capital that is required to finance the green projects is generally considered high, and mostly acts as a barrier either in the public or private sectors (Sun et al., 2023). Also, high risks related to long payback periods of green investments, including renewable energy infrastructure, also poses a significant challenge to implementation of sustainable investing. This underlines the importance for governments as well as international organisations to build an environment in which undertaking green investments is low-risk and where rewards for establishing sustainable business models are attainable (Elshaer et al., 2023).

In conclusion, the study highlighted a positive correlation between green finance and a reduction of CO2 emissions but also noted new emerging positive and negative impacts. In their case too, green finance has played a better role than developed economy in environmental conservation, emission reduction, and supporting eco-innovation but the impacts have been rather less due to institutional impedance, financial constraints, and lack of access to the capital market. This means that these challenges need to be addressed so that green finance can attain its full potential of reducing global CO2 emissions by developing better governance, increasing green finance accessibility amongst the populace, and giving long-term backing to clean technologies.

H1: Green finance has a significant negative relationship with global CO2 emissions.

*1.2. Renewable Energy and CO2 Emissions*

The share of renewable energy in the fight against the use of fossil resources and CO2 emissions has been receiving increased attention in the last couple of years. Renewable energy would encompass solar, wind, hydro and bio energy and is a critical element in addressing climate change globally. Emerging evidence proves that using renewable energy reduces CO2 emissions since renewable energy replaces fossil fuel-based energy that produces the largest amounts of emissions. Many empirical papers as shown in Table 2 like (Wu, 2023; Jin et al., 2023; Sun et al., 2023; Sadiq et al., 2023; Ali et al., 2023) have corroborated the relationship between the deployment of renewables and the reduction of carbon intensity and total CO2 emissions.

A highly detailed examination of this topic is presented in Wu (2023), which investigates the consumption of renewable energy in OECD nations and its effects on CO2 emissions. Employing a Generalized Method of Moments (GMM) model, the research reveals that a 1% rise in renewable energy use leads to a notable decrease in CO2 emissions, supporting the case that renewables are crucial for attaining carbon neutrality. Additionally, this study emphasizes that investments in renewable energy within developed countries assist in alleviating the adverse environmental impacts of industrialization while fostering sustainable economic development.

**Table 2.** Summary of Key Studies on Renewable Energy and CO2 Emissions.

| Author/Year | Methodology | Results | Contributions | Limitations |
|---|---|---|---|---|
| Wu (2023) | GMM, Fixed Effects Model | Renewable energy consumption significantly reduces CO2 emissions in OECD countries. | Comprehensive analysis of renewable energy in developed economies. | Focuses on OECD countries; lacks insights into developing economies. |
| Jin et al. (2023) | GMM, Panel Data Analysis | A 1% rise in renewable energy consumption improves carbon neutrality by 0.048% in OECD countries. | Highlights renewable energy's role in carbon neutrality. | Limited exploration of the long-term economic impacts of renewable energy. |
| Sun et al. (2023) | NARDL, Time Series Data | Renewable energy investments reduce CO2 emissions in China but need further expansion to meet targets. | Focus on China's renewable energy transition and emissions reduction. | Limited applicability to other developing regions. |
| Sadiq et al. (2023) | CS ARDL, Panel Data Analysis | Renewable energy consumption reduces CO2 emissions in BRICS countries but with varying effectiveness. | Explores the role of renewable energy in emerging economies. | Lacks sector-specific insights. |
| Ali et al. (2023) | RALS co-integration and QARDL | Renewable energy has potential in South Asia but faces barriers like financing and institutional weaknesses. | Highlights challenges in scaling renewable energy in developing regions. | Focuses on barriers without providing detailed policy solutions. |

Source: Compiled by the authors.

Jin et al. (2023) have also established the benefits of the consumptions of renewable energy with empirical studies; for each percentage increase in the consumption of renewable energy, carbon neutrality improves by 0.048% in OECD countries. This finding therefore supports the use of renewable energy so as to reduce the continued dependence on the fossil energy and therefore decrease emissions of the greenhouse gases. Both onshore wind and solar power are strategic for decarbonizing industrialized countries' economies and for achieving climate change objectives including the Paris Accord.

As is still reflected in the emissions reduction impact they have produced in developing regions. In their study on China's renewable energy development and its role toCO2 emission reduction, Sun et al. (2023) they emphasize the achievement that has been recorded. In this study, the Nonlinear Autoregressive Distributed Lag (NARDL) model is applied to an investigation into the extent to which the levels of renewable energy investment affect CO2 emissions in China. China, being one of the biggest carbon contributors in the world has the positive effect of rising demand for less carbon emitting energies such as hydro and solar power. However, the work also points out that additional investment into renewable energy system in order to support the given Chinese carbon emission cuts is still required.

Sadiq et al. (2023) goes further by looking at the BRICS countries in their study. To investigate the impacts of renewable energy consumption on the emission reduction in these emerging economies, the paper employs the CS ARDL technique. Analysing the results, it can be concluded that the consumption of renewable energy leads to a significantly lower CO2 emission; there is a dependency between the level of economic development and the assessment of the energy infrastructure of each country. The conclusion points more to maintaining an increased focus on investing renewable energy sources to maintain progress on reducing emission in countries which have intently placed a reliance in the fossil fuel for economic growth.

This study therefore identifies some challenges with proof of positive impact of renewable energy consumption on CO2 emissions as follows; In South Asia, Ali et al. (2023) maintain that despite the fact that renewable energy may help decrease emissions, there are important limitations to increasing renewable energy capacity. They pointed out a relative scarcity of financing structures, insufficient technology knowledge, and feeble institutional environment as big challenges to the development of renewable energy in the developing countries. These challenges ensure that the region cannot afford to drop the use of fossil fuels and embrace clean energy as and when is legally required.

In general, the results reveal that renewable energy consumption is much negatively related with CO2 emissions and helps decrease the global demand on fossil energy sources. But for the renewable energy to exert higher influence, more investments must be made, backed by institutions and technologies which have to be advanced more so in the developing world. This paper clearly highlights the importance of the generation of renewable energy in the fight against CO2 emission and climate change. Renewable energy has been found to bear sufficient impact in developed and even developing countries, but for optimal impacts, various impediments including financial and institutional issues have to be dealt with.

H2: Renewable energy consumption has a significant negative relationship with CO2 emissions.

*1.3. Economic Growth and CO2 Emissions*

Economic development has been assumed to mean a rise in the CO2 emissions particularly through energy use alongside industrialization. But, the Environmental Kuznets Curve (EKC) hypothesis postulates that although emission may increase with economic growth in the early stage of development similar to the Kuznets curve hypothesis, emissions will decrease thereafter following development of better emission controlling technologies. The contention that economic development is proportional to carbon emissions forms an inverted Kuznets curve because after reaching their developmental peak nations shift their focus on energy efficiency technologies and renewable energy sources.

The EKC hypothesis has therefore been synthesised in different studies giving different outcomes based on the level of economic development and the type of technologies that have been used. For example, Jin & Wang (2023) established the empirical study to justify EKC hypothesis in the OECD countries, where economic development causes increased emissions during the process of development. Yet, with time the rates of emission had started rising as these countries embraced cleaner sources of energy and more sustainable industrial practices. Table 3 also shows that each one percent increase in the initial values of the GDP results in an increase in the rate of CO2 emissions, but this is actually sustained by the adoption of green technologies that reduces the emissions in the subsequent periods thus supporting EKC hypothesis.

Similar to this study, Wu (2023) investigates the direct CO2 emissions and economic growth nexus in OECD countries and applies the GMM model. Analysing the relationship between economic growth and emissions, the research discovers that economic growth first increases emissions, but investments in renewable energy and green finance reduce the emissions that result from growth. The findings also show that post growth effects point a country to spend more in cleaner technologies hence emerging at lower emission levels in the next periods. This is particularly true given that development of the green economy is possible in high income countries where acquisition of the necessary financial capital and technologies is easiest.

In developing areas, the support for the EKC hypothesis is not as consistent. Research by Ali et al. (2023) focuses on South Asian nations, revealing that during the initial phases of industrialization, economic growth still results in increased emissions due to a strong dependence on fossil fuels. The study underscores the obstacles these countries encounter in transitioning to cleaner technologies, such as limited access to green financing, fragile institutional structures, and inadequate technological infrastructure. Consequently, the EKC pattern is less apparent in these economies, where emissions continue to rise alongside growth, unlike the decline observed in more developed regions.

**Table 3.** Summary of Key Studies on Economic Growth and CO2 Emissions.

| Author/Year | Methodology | Results | Contributions | Limitations |
|---|---|---|---|---|
| Jin et al. (2023) | GMM, Panel Data Analysis | Economic growth initially increases CO2 emissions, but emissions decline as economies adopt cleaner technologies, supporting the EKC hypothesis. | Focus on OECD countries; highlights the role of clean technology in emissions reduction. | Limited applicability to developing regions. |
| Wu (2023) | GMM, Fixed Effects Model | Economic growth initially increases CO2 emissions, but renewable energy investments help reduce emissions over time. | Provides empirical support for the EKC hypothesis in developed economies. | Focuses on high-income countries; limited insights into developing regions. |
| Ali et al. (2023) | RALS co-integration and QARDL | Economic growth increases CO2 emissions in South Asia due to reliance on fossil fuels, with limited evidence of the EKC hypothesis. | Highlights the challenges developing countries face in adopting cleaner technologies. | Limited access to green finance and weak institutional frameworks delays the EKC curve. |
| Sadiq et al. (2023) | CS ARDL, Panel Data Analysis | Economic growth increases CO2 emissions in BRICS countries, though green technology adoption is beginning to reduce emissions in some countries. | Explores the EKC hypothesis in emerging economies like BRICS. | Incomplete EKC pattern in emerging markets where green technology adoption is still limited. |

Source: Compiled by the authors.

Likewise, Sadiq et al. (2023) examine the EKC hypothesis in Brazil, Russia, India, China, and South Africa which are the members of the 'BRICS' nations. A cross-sectional autoregressive distributed lag (CS ARDL) model is employed in their study to test the effects of economic growth on CO2 emissions. The findings presented in the paper indicate that few of the BRICS countries especially China has started enjoying the opportunities associated with the investment social capital in environmental technologies and renewable energy, however, economic growth remains linked to increased emission. This implies that the EKC hypothesis is only valid to some extent in emergent economies where there are ongoing processes of transformation into cleaner energy technologies.

The contradicted findings of the individual studies regarding regional affiliation stress the role of economic and technologic domains for collecting the connection between composite improvement and CO2 emissions. EKC hypothesis is more relevant in the context of high-income country having proper institutional facilities and access to green finance because they possess money to invest on new technology. But, in L&DEs, as financial and technology factors remain stringent, the economic growth triggers emission contrary to the decoupling observed by EKC hypothesis.

This analysis shows that the fact that the EKC hypothesis holds for any region depends on the extent to which the variables in the model vary within that region. Thus, on the one hand, the EKC hypothesis is valid in developed economies because investments in cleaner technologies are more feasible in these countries than in developing and emerging ones, on the other hand the relationship between economic growth and emissions in the developing and emerging economy is more complicated. In these regions, the absence of green finance and the technology to support it has not shifted towards emissions reduction hence lowering the relevance of the EKC hypothesis. This implies that specific polices instruments, enhanced spending on renewables and better institutional environment are required to ensure that EKC pattern prevails in developing countries.

**H3:** Economic growth has an inverted U-shaped relationship with CO2 emissions, where emissions initially rise with economic growth but eventually decrease as cleaner technologies are adopted.

Furthermore, it is essential to highlight that the interplay between environmental factors and social and economic dimensions has been extensively explored in numerous scholarly works within the framework of sustainable development. Notably, these studies address sustainability from various perspectives, such as the integration of ecological and economic aspects in fostering sustainable progress (Kwilinski et al., 2023b; 2023c; 2024b; 2024e; Kwilinski & Vysochyna, 2024; Kwilinski, 2024b; Kharazishvili et al., 2020), the role of reflexive management in achieving homeostasis through adaptive strategies (Zimbroff, 2023; Surya et al., 2024; Payonk et al., 2015; Lyulyov et al., 2020; Kyrylov et al., 2020; Kwilinski et al., 2024f; Kwilinski et al., 2022; Gigauri et al., 2024; Dacko-Pikiewicz, 2019b; Berg & Spicka, 2023; Khalifa et al., 2024), and advancements in energy management for optimizing resource use and promoting resilience (Ziabina et al., 2023; Mlaabdal et al., 2024; Kwilinski et al., 2024a; Kwilinski, 2024b; Kharazishvili et al., 2021; Karpenko et al., 2018). Additionally, a substantial body of literature examines the critical role of digitalization in achieving various sustainable development goals, emphasizing its transformative potential in driving innovation and efficiency (Lyulyov et al., 2024b; Labudova & Fodranova, 2024; Kwilinski et al., 2024d; 2024c; 2023d; 2023a; Kwilinski & Kardas, 2024a; Khalifa et al., 2023; Kwilinski, 2023; 2019; Kharazishvili et al., 2022; Infante-Moro et al., 2022b; 2022a; Dementyev et al., 2021; Boyko et al., 2024; Hossain et al., 2024; Ayala-Mora et al., 2023).

## 2. Methodology and data

This study investigates the long-run relationships between CO2 emissions (CO2EMW) and three key independent variables: Therefore, the variables of interest are global GDP (LGDPW), green finance (LGFLD) in developing countries, and global renewable energy consumption (LRECW). The study uses the Autoregressive Distributed Lag (ARDL) model which is a standard econometric model for the short and long-run relationship analysis of integrated variables data at order of integration I(0) or I(1) (Sadiq et al., 2023; Sun et al., 2023). Consequently, the present study is appropriate for employing the ARDL model, designed for defining intricate interactions between environmental factors, economic growth, and financial flows toward sustainability.

The most suitable features of the ARDL model to engage in this study are that it is capable of estimating short-term and long-run paths and equilibrium association. The general form of the ARDL model is expressed as follows:

$$(\mathrm{CO2EMW}) = \alpha_1 + (\mathrm{LGDPW})_t + (\mathrm{LGFLD})_t + (\mathrm{LRECW})_t + \varepsilon_i \quad (1)$$

where , CO2EMW – CO2 emissions dependent variable; LGDPW – global GDP as independent variable; LGFLD – Green Finance independent variable; LRECW – global renewable energy consumption.

As Hasem and Pesaran (1997) have suggested, to start with the study uses a bound testing procedure to check for the presence of long run equilibrium relationship between CO2 emissions and the variables of interest. This test is based on F-statistic and Kao & Chiang (1999) concluded that this test can be used to compare either the null hypothesis that components are not co-integrated, against the alternative that at least one of the components is co-integrated (H_0: β_0^i = β_1^i = 0). The test yields two critical values: As is confirmed by, all the variables is I(0) or at the lower bound for I( 1) variables. Long-run relation where co-integration is established is given by the fact that the calculated F-statistic surpasses the upper critical value (Sadiq et al., 2023).

The ARDL co-integration model is expressed as:

$$\Delta\ \ln\ (\mathrm{CO2EMW})_{t-1} = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\ \Delta\ \ \ln\ (\mathrm{CO2EMW})_{t-1} + \sum_{i=0}^{p} \alpha_{2i}\ \Delta \ln\ (\mathrm{LGDPW})_{t-1} + \sum_{i=0}^{p} \alpha_{3i}\ \Delta \ln\ (\mathrm{LGFLD})_{t-1} + \sum_{i=0}^{p} \alpha_{4i}\ \Delta\ (\mathrm{LRECW})_{t-1} + \beta_1\ \ln\ (\mathrm{CO2EMW})_{t-1} + \beta_2 \ln\ (\mathrm{LGDPW})_{t-1} + \beta_3 \ln\ (\mathrm{LGFLD})_{t-1} + \beta_4\ (\mathrm{LRECW})_{t-1} + \mu_i \tag{2}$$

where , α1i, α2i, α3i and α4i stand for the short-run parameters. Lagged levels of the variables represent the long-run equilibrium relationship among the variables. From the co-integration equation, we determine the Error Correction Term (ECT), which helps us understand the rate at which the dependent variable returns to its long-run equilibrium following a short-run disturbance. Consequently, the error correction model offers insights into both the short-term fluctuations and the long-term trends of CO2 emissions in relation to the independent variables. The parameter θ represents the error correction term, indicating the speed at which CO2 emissions adjust back to their long-term average after experiencing a short-term shock.

$$\Delta \ln\ (\mathrm{CO2EMW})_{t-1} = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i}\ \Delta \ln\ (\mathrm{CO2EMW})_{t-1} + \sum_{i=0}^{p} \alpha_{2i}\ \Delta \ln\ (\mathrm{LGDPW})_{t-1} + \sum_{i=0}^{p} \alpha_{3i}\ \Delta \ln\ (\mathrm{LGFLD})_{t-1} + \sum_{i=0}^{p} \alpha_{4i}\ \Delta\ \ (\mathrm{LRECW})_{t-1} + \theta\ ECT_{t-1} \tag{3}$$

Where θ – the error correction term.

In checking the reliability of the applied ARDL model, some diagnostic tests are carried out as follows: In other words, the Durbin-Watson test is inadequate in detecting autocorrelation in models that contain lagged dependent variables and that is why Breusch-Godfrey test is preferred. Jarque Bera statistic any residual data to check normality of the data using the skewness and kurtosis coefficients and requires the original model be normal. Furthermore, homoscedasticity, whereby the variance of the residuals does not vary with the measure of analysis is checked because heteroscedasticity of the residuals is statistically invalid for making correct inferences of statistical value in the study (Verbeek, 2017).

In this regard, the following diagnostic tests are implemented in the study to check the completeness of the model, the absence of econometric problems in the model results, including serial correlation, heteroscedasticity and non-normal residuals. This discussion of the data and the interactions between the variables offers a good basis for further analysis of long-run co-integration between global GDP, green finance, and renewable energy intake and CO2 discharge.

This work employs quarterly data for both the pre- and post-2000 periods up to 2021 from sources like the World Bank. Data for green finance (LGFLD), also referred to as international financial flows to development countries in support of global clean energy research, development and utilization of renewable energy, is obtained from Our World in Data. In this case, to obtain quarterly series from the available annual data, the study applies the Gandolfo (1981) disaggregation formula whereby quarter data is obtained by the following quadratic formula Current, lagged, and lead annual values are integrated in the formula to obtain the respective quarter data (Ali et al., 2023; Jin et al., 2023). This method helps to avoid deviations from the quarterly values to be derived and to make them consistent with long-run annual patterns observed.

The dependent variable which is used in this study is the CO2 emissions (CO2EMW), which measures carbon dioxide emission from all countries of the world in kilotons. This variable is often employed by environmental researchers to evaluate the effect of economic activities on global environment (Chu et al., 2023; Hossain et al., 2023a; Hailiang et al., 2023). The independent variables include:

1. Renewable Energy Consumption Worldwide (LRECW). This one indicates the share of total final energy demand satisfied by renewable energy internationally. It is a vital pointer to the change in the global energy trend and the ability of renewable energy to influence the reduction of CO2 emission (Le & Taghizadeh-Hesary, 2020; Mngumi et al., 2022, Ogede & Tiamiyu, 2023).
2. Global GDP (LGDPW). This indicator denotes the global gross domestic product measured in constant 2015 US dollars. It functions as an indicator of economic expansion, associated with heightened energy consumption and emissions, but may also stimulate investment in cleaner technologies, in accordance with the EKC theory (Shahbaz et al., 2013; Shoaib et al., 2020; Hossain et al., 2023b).
3. Green Finance (LGFLD). International flows of finance for development of developed countries to support clean energy projects and renewable energy sources. Simply, green finance is another polarity that is used to combat climate change by ensuring the transformation of energy sources to sustainable energy (Bakry et al., 2023; Ran et al., 2023; Cao, 2023).

## 3. Results

It is crucial to emphasize that prior to estimation, the ARDL model must assess the stationarity of the time series data in order to prevent the problem of spurious regression. For this purpose, the stationarity of the variables is evaluated using the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test, both at level and/or first differences.

Table 4 shows the results of the unit root tests of LCO2EMW as dependent variable and LGDPW, LGFLD and LRECW as the independent variables. It is revealed that while there are some mixed results at the levels, all the variables are integrated of order one, I(1), at their first differences, implying that the variables has unit root at level and stationary at the first difference.

**Table 4.** Unit Root Tests.

| Variables | Levels (ADF Test) | Levels (PP Test) | First Differences (ADF Test) | First Differences (PP Test) |
|---|---|---|---|---|
| LCO2EMW | -1.81 | -3.88*** | -5.59*** | -5.76*** |
| LGDPW | -0.81 | -3.17** | -6.29*** | -5.70*** |
| LGFLD | -1.79 | -1.99 | -2.32 | -5.71*** |
| LRECW | -2.15 | -4.44*** | -4.1*** | -5.79*** |

Note: *** indicates significance at the 1% level, ** indicates significance at the 5% level. $H_0$: The null hypothesis corresponds to non-stationary.
Source: Compiled by the authors.

The result of the ADF test indicated that none of the variable under consideration is stationary at the levels. Nonetheless, the PP test shows that all the series LCO2EMW, LRECW, and LGDPW is stationary at the 1% level while LRECW at 5% level. According to the ADF and PP tests, all the variable is stationary at both levels as well as at the first difference signifying that all the variable is I(1). These findings explain the use of the ARDL model for the examination of the long-run association of the variables.

The second step in the analysis process is to examine whether some of the variables bear a long-run relationship (co-integration). Critical values are then compared to the F-statistic which has been calculated in the ARDL bounds test. If the F-statistic is equal to or higher than the upper bound of the critical values then co-integration is said to exist which also shows the long run equilibrium relationship between variables (Hasem & Pesaran 1997).

The results of the bounds test of LCO2EMW model are shown in the table 5. The F-statistic of 3.46 for the current analysis is higher than the upper bound critical value of 2.63 when using a 5 percent significance level, which provides significant evidence toward co-integration. This indicates that the saved CO2 emissions are inversely related to the independent factors of global GDP, green finance, and renewable energy usage over the long term.

**Table 5.** Bound Test Results.

| Dependent Variable | F-statistic | 10% (I(0)/I(1)) | 5% (I(0)/I(1)) | 1% (I(0)/I(1)) |
|---|---|---|---|---|
| LCO2EMW Model | 3.46** | 2.37 / 3.2 | 2.79 / 3.67 | 3.65 / 4.66 |

Note: ** indicates significance at the 5% level.
Source: Compiled by the authors.

However, the results of co-integration confirm the presence of long-run relationship between global economic growth, green finance, and renewable energy consumption, and CO2 emissions. This result is similar to previous research in this line that underscores the need to adopt renewable energy and sustainable funding patterns to address emissions (Bakry et al., 2023; Xu et al., 2023).

Table 6 shows long-run relations between the variables, the model is estimated using the bound testing technique of the ARDL approach. The long-run coefficients of the LCO2EMW model are shown in Table 3 to understand the influence of each explaining variable on CO2 emissions.

**Table 6.** Long-Run Estimated CO2EMW Model – Developing Countries.

| Dependent Variable | C | LGDPW | LGFLD | LRECW |
|---|---|---|---|---|
| CO2EMW | 1.94 | 0.48*** | 0.01 | -0.77*** |

Note: *** indicates significance at the 1% level.
Source: Compiled by the authors.

The results indicate that economic growth positively influences CO2 emissions at a significance level of 1%. It was established that an increase of one percent in global real per capita GDP correlates with an average rise of 0.48 percent in CO2 emissions, holding other factors constant. This result aligns with prior studies conducted on the relationship between economic growth and rising emissions, attributed to heightened industrial activities and energy consumption (Akhtar et al., 2023; Hamurcu, 2023). In addition, the log run model indicates positive relationship between green finance and CO2 emissions, with coefficients that lack statistical significance. In fact, an assessment of the current state of green finance in developing nations indicates that reducing emissions is quite challenging. This aligns with the findings of Su et al. (2021) and Li et al. (2022), who argue that the scale and effectiveness of green finance in these regions remain insufficient to influence emissions significantly. However, this perspective contrasts with research by Cao (2023) and Ran et al. (2023), which explores the potential of green finance to mitigate these losses. Furthermore, the findings indicate that renewable energy consumption exerts a substantial and adverse impact on CO2 emissions at the 1 percent significance level. An increase of one percent in renewable energy usage leads to a notable reduction in CO2 emission levels by approximately one percent, thereby contributing significantly to environmental conservation. This outcome aligns with numerous studies emphasizing the importance of renewable energy in reducing emissions (Ren et al., 2020; Mngumi et al., 2022; Latif et al., 2023).

These results raise the questions about how to achieve sustainable development of economy and maintenance of the environment. The economic development raises the emissions while renewable power consumption reduces them; therefore, more policy should encourage renewable power to reduce the pollution that comes with the economic development.

A set of model diagnostic tests were accomplished in this study to test the coherence of the specified ARDL model such as testing for serial correlation and heteroscedasticity. As shown in Table 7 below, the diagnostic tests for the LCO2EMW model have been conducted.

**Table 7.** Diagnostic Test Results.

| Test Statistic | LCO2EMW Model | Probability |
|---|---|---|
| B: Serial Correlation | 0.96 > 5% | No correlation |
| C: Heteroscedasticity | 0.62 > 5% | No heteroscedasticity |

Source: Compiled by the authors.

The diagnostic test confirms that there is no serial correlation and or heteroscedasticity – the model is therefore valid. The results show that there is no serial correlation hence the residuals are independently distributed while heteroscedasticity test proves that variance of the residuals is constant across observations. These results ensure the credibility of the ARDL model and increase confidence in estimating coefficients with high accuracy and efficiency (Verbeek, 2017).

Table 8 illustrates the short-term dynamics and the long-term equilibrium relationship between CO2 emissions and the independent variables, as assessed by the ECM. The ECM coefficient is negative and statistically significant at 1% level implying the speed of adjustment which captures how fast CO2 emission reverts to its long-term level after a short run shock.

**Table 8.** ECM Coefficient.

| Dependent Variable | ECM Coefficient | Significance Level |
|---|---|---|
| CO2EMW Model | -0.03 | 1% |

Source: Compiled by the authors.

Hypothesis H2, which predicted a negative and significant ECM coefficient, is also supported in the present study. The coefficients for balance are long-run equilibrium since adjustment, coefficients reveal that CO2 emissions return to equilibrium at about 3 percent per quarter. This provides additional evidence for co-integration as was revealed by the bounds test.

The outcome of an empirical analysis shows that economic growth leads to an increase in CO2 emission in the long run under the constant term, whilst the usage of renewable energy has a negative effect on emissions out the constant term. Though green finance in developing countries is found positive but not significant, the following conclusion can be made.

## 4. Discussion

The study's empirical findings shed light on the long-term relationships between CO2 emissions and three key independent variables: global GDP, green finance in developing nations, and global renewable power systems consumption. From 2000 to 2021, employing the quarterly data and Autoregressive Distributed Lag (ARDL) model with the fixed effect, the research establishes that economic growth significantly influences the rise in CO2 emissions, while renewable energy consumption is of outmost importance in lower emissions. However, there is no significant statistically significant relationship between green finance and the emission level in developing countries. These findings are consistent with and at times contrary to extant literature as well as provide theoretical contributions and policy suggestions for CO2 emission reduction and sustainable advancement.

Economic Growth and CO2 Emissions: The results support a positive and significant coefficient for global GDP and CO2 emissions, as concluded in prior literature. One percent rise in the global GDP results into 0.48 percent increase in the global CO2 emissions Rates showing that growth in economic activities calls for higher energy utilization, specifically from the conventional sources of energy such as the fossil energy sources thus increasing emissions (Akhtar et al., 2023; Hamurcu, 2023). This relationship depicts all the more the antagonistic bipolarity of development and environment where growth of industries and increased energy consumption result in pollution.

This finding is consistent with the Environmental Kuznets Curve (EKC) hypothesis that predicts that emission rises with economic growth in the lower stage of development but reduces in higher stage due to technology improvement and policy intervention (Jin et al., 2023; Xu et al., 2023). However, the current findings do not show this downward trend in emissions, thus indicating that global economic growth still hinges on the exploitation of carbon industries.

The study also confirms the validity of the EKC hypothesis used to forecast the direction of the social relationship between GDP and CO2 emissions. Yet, the failure to observe an inversion of this parabolic pattern in the present research indicates that decoupling of society from fossil fuels for cleaner energy has not yet reached a mature global stage. This creates more theoretical issues about the rate of commercialization of green technology in the developed and the developing world. The results also point out that adding technological advancement and energy variables defers may give further subtle correlation between growth and emission (Su et al., 2021; Ye et al., 2022; Ullah et al., 2023). Moreover, it is relevant to look deeper at the part played by the environmental regulations and policy adjustments on this concern.

Policy makers continue to be fixated with the problems of disconnecting between growth and environmental detriment. The findings of this study suggest that green investments including renewable energy technologies are viable for creating energy Efficiency without constraining growth. Governments need to invest in research and development of clean energy technology since industrialization affects the environment (Soundarrajan et al., 2016; Zhang et al., 2021; Khan et al., 2024; El-Aidie & Khalifa, 2024). Policies, which include subsidies for energy efficient equipment and technologies, carbon taxes, and increased standards of emissions could also be used to decrease carbon intensity of the economic activities (Su et al., 2021). However, the rapid industrialization in developing countries that requires economic growth to lift people out of poverty has imposed the long-term cost of adapting the environment to support these changes.

The empirical evidence in this study reveals that green finance is significantly related with CO2 emissions, although the relationship is not significant at the 5 percent level of significance for developing countries. Recent levels of green financial flows in the regions, according to the analysis, are only 0.01 for green finance, which means they are still low and incapable of exerting pressure to reduce emissions. This discovery deviates from the anticipated hypothesis that green finance, often as an investment in sustainability and clean energy projects, should partner for emissions reduction (Cao, 2023; Ran et al., 2023). Inefficiencies in project implementation, inadequate scale, and institutional barriers that work against the optimal uses of funds may also explain why green finance has had limited success (Su et al., 2021; Li et al., 2022).

Still, green finance may fail to cut emissions because these investments are comparatively small, given the size of the problem. Bridging the green finance audit reveals that developing nations cannot effectively deploy Green funds where such investments will be most impactful due to weak fiscal institutions and governance (Ren et al., 2020; Wang et al., 2021). Moreover, owing to the long-term horizons of green finance investments, their impact on emissions reduction can hardly be seen even if substantive investments are made, especially where projects are still in their planning phases (Gherbi, 2020).

The fact that virtually none of this money experiences green finance challenges the conventional notion that financial flows for sustainable objectives will always make an impact by reducing emissions. This raises the fundamental question of what circumstances make green finance possible. Perhaps other variables such as institutional quality, governance, or the absorptive capacity of developing nations might have to be included in theoretical frameworks for the purposes of understanding the dynamics in the relationships between green finance and EMISSIONS, as suggested by Xu et al., (2023). Furthermore, the matter of 'time delay' between investment in green projects and the espoused environmental results is an issue Another point of interest that has to be taken under consideration is the evaluation of green finance Both implementation and monitoring of environmental results require time For such reasons, the so-called time delay between investment in green projects and concrete environmental outcomes has to be taken into consideration during the evaluation of the impact of green finance (Wang & Ma, 2022)

To enhance effectiveness of the green finance in reducing emissions, policy makers should therefore focus on the issues hindering efficient use of the finance. This includes reinforcing institutional arrangements, enhancing the evaluation mechanism for the project's suitability of receiving green finance and promoting the flow of green finance to the suitable projects that have high abatement potential (Bakry et al., 2023). Global and multilateral funding agencies and providers should also aim to scale up the extent of green finance in developing nations to correspond with the areas of the climate ambition (Meo & Abd Karim, 2022). The information to be derived from the case studies of green finance projects, for instance, could reveal emerging patterns of success and implementation models that could be adopted elsewhere (Ren et al., 2020). In addition, governments should design the policy environment for private investments in green projects and make sure that even financial instruments, like green bonds, are useful and available (Wang & Ma, 2022).

The finding regression analysis model indicates a negative and statistically significant relationship between renewable energy and CO2 emissions. Specifically, the findings demonstrate that a one percentage point increase in renewable energy consumption leads to a 0.77 percent decrease in emissions, highlighting the crucial role of renewable energy in mitigating harmful environmental impacts. This aligns with various studies that emphasize the numerous benefits of transitioning from fossil fuels to renewable sources such as solar, wind, and hydropower (Latif et al., 2023; Mngumi et al., 2022; Lu, Liu, Mohsin & Zhang, 2023).

The negative correlation between renewable energy and emissions indicates the need to increase the capital in renewable energy systems worldwide. The findings also show that Low carbon has become achievable by affording the renewable energy implying that the countries which have invested have been able to cut on their emissions while at the same time achieving economic growth as renewable energy improves energy security and steadiness of economic growth (Zefang et al., 2023; Nawaz et al., 2021). Nevertheless, the growth and development of renewable energy sources face certain problems, especially in emerging economies where there may exist some constraints in the form of finicial, technical and institutional-environmental conditions which may hamper the implementation of clean energy technologies.

On this account, findings on the substantial role of renewable energy in terms of emission reduction align with theoretical frameworks proposed earlier by Xu et al., 2023; and Latif et al., 2023 that argue that renewable energy has substantial environmental benefits. This finding supports the role of renewable energy in attaining sustainable environment goals in the long run. However, the study also has implications for the ease of transition to renewable energy in the developing world where deployment challenges are higher (Lu et al., 2023). Such theories should also take into account the certain peculiarities of the development of these countries and to determine how the cooperation with other countries and the financial aid can contribute to the shift towards the renewable energy sources (Nawaz et al., 2021).

Government and policy makers should focus on such policies that may help in developing renewable energy sources infrastructure. This is in form of grant for organizations and individuals to shift to the use of renewable energy sources like subsidies towards installation of solar and wind power (Hailiang et al., 2023). Furthermore, it is needed in increasing the size of the renewable energy projects mainly areas that suffer from shortage in capital and technology (Bakry et al., 2023). Donors of international relations and financial institutions should act in order to boost the development of renewable energy sources in the developing countries, ensuring that the finances are used in the right way, and the aim of the renewable energy projects implemented is achieved (Latif et al., 2023).

Policy makers should also ensure that there is the incorporation of renewable energy into country's development plans so that therefore, economic growth and carbon emissions are separated. This could include, setting realistic targets on renewable energy generation systems, upgrading the grid to handle the variability of the renewable resources, as well as the development of effective energy storage solutions for the renewable systems which face variability problems (Hailiang et al., 2023). Ongoing assessment of the implemented renewable energy policies will be crucial to guarantee continuous advancement and adaptability in policy measures to improve the influence of renewable energy on emission amelioration (Lu et al., 2023).

The findings of this study have some major implications for policy makers interested in the management of the global level of CO2 emissions and economic growth. First, to meet the argument about link between economic growth and emissions, government should put effort in research and development in technology, which can cut down the intensity in emission of carbon through industrial development. This can be done by raising public investment in research and development (R & D) of green energy technologies in order to support sustainable green economy (Soundarrajan et al., 2016; Zhang et al., 2021). Furthermore, encouraging the labour and technology intensive production can also bring new economic development while minimizing the negative effect of growth on environment (Zhang et al., 2021).

However, more efforts are required by the policymakers to ensure that the aspect of green finance is well governance and implement and this will go along way in increasing the efficiency of green finance. This involves adapting to challenges like institutional voids, and insufficient experience, which hinder the application of green finance especially in the developing areas (Ren et al., 2020; Bakry et al., 2023). When more resources are devoted to the promotion of green finance, specifically, when governments guarantee that such funds will be allocated to projects with maximum high possible emissions reductions then significant progress can be achieved to address climate change (Wang & Ma, 2022).

The effect of renewable energy on emission indicates the outstanding potential of investing in renewable energy structure. Governments should develop that encourage the use of renewable energy, and offer subsidies for the enhancement of renewable energy technologies (Hailiang et al., 2023). This way, policymakers are guaranteed of economic growth without consequential emissions through exploitation of renewable energy sources (Xu et al., 2023; Latif et al., 2023).

## Conclusions

This paper analysed and modelled the long run relationship between variables such as gross world product, CO2 emission, green finance in developing countries and gross renewable consumption using Autoregressive distributed lag approach. These are highlighted to show that there is a positive relationship between economic growth and CO2 emissions the implication for which is the utilization of fossil energy that results from industrialization. However, the variable that stands out as being most important for reducing emissions is the consumption of renewables showing a very high coefficient of negative influence on CO2. But the results of green finance on developing countries was discovered to be insignificant, this therefore confirms that the current level and usage of green finance is not enough to cause variation in emissions reduction.

The findings should go a long way to highlight that strategies on economic development must take into consideration the balance that needs to be made of the negative impacts of industrialization through using energy from renewable sources as well as adopting an innovative automatic green technology system. Meanwhile, green finances remain weak and ineffective in developing countries to meet the increasing demand of renewable energy investment, thus, there is need to enhance the governance quality and concentration of such financial flows. The findings also help affirm the Environmental Kuznets Curve hypothesis but with the understanding that many economies are yet to graduate to a phase where economic development leads to decreased emission.

While the research showcases remarkable strengths, it also presents several limitations. The data utilized for green finance did not differentiate between financial instruments or projects, which may obscure the impact of specific investments, such as those in renewable energy or eco-innovation initiatives. Additionally, issues related to data integrity or the absence of information, particularly from developing countries, could have hindered the accuracy of green finance statistics. The study also assumes constraints from technological changes and policy variables, as these elements could significantly alter the trends in economic growth and emissions. Furthermore, the analysis focused on global job creation patterns without considering potential regional differences that could influence the effectiveness of green finance and renewable energy policies across various economic and institutional contexts.

Future research should expand on them by employing more detailed green financing data such as individual financial tool exposure and targeted sectors to more accurately estimate their effects on emissions. Technological progress, utilizing efficient energy consumption, policy levers should also be incorporated in order to capture these factors in relationship with economic development. Further, region based analysis would provide more information about the divergence of the impact of green finance, renewable energy and economic development across different regions. It was also suggested that examples of existing effective green finance projects in developing countries could simply offer insights on how to proceed in the future. These areas should be addressed in future studies to improve the comprehension of patterns that would best help in achieving lower levels of global CO2 emissions in tandem with sustainable development.

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