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Original Research

Green Finance and Globally Competitive and Diversified Production: Powering Renewable Energy Growth and GHG Emission Reduction

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Abstract

Increased greenhouse gas (GHG) emissions have triggered a global climatic shift that threatens all species. The last century witnessed many improvements in several industries that elevated GHG emissions to levels not seen in several years. Energy usage is a major source of GHG emissions. The current study will examine how green finance and economic fitness (globally competitive and diversified production) synergistically affect GHG emissions and renewable energy growth. GMM, FMOLS, and quantile regression were used to analyze the OECD economies. Green financing and economic fitness reduced GHG emissions and increased renewable energy use in all three models. The synergistic effect of green financing (GF) and economic fitness (EFI) shows that nations can significantly mitigate the emission of greenhouse gases (GHGs) and encourage the adoption of renewable energy sources. Green financing and economic fitness (EFI) seem to work better in high-carbon economies than in low-carbon ones. GF has a greater impact on greenhouse gas (GHG) emissions in countries with higher emissions. In both high- and low-emission countries, good governance, regulatory frameworks, economic risk, and developed human capital help reduce greenhouse gas emissions. However, GDP affects GHG emissions positively in all OECD countries. Moreover, GDP, effective government, quality regulations, economic risk, and human capital promote renewable energy use in economies. Private enterprises and households need financial incentives to adopt renewable energy technology quickly. Businesses may finance environmental projects without government assistance. Complex and varied product manufacturers are encouraged to employ renewable energy and minimize greenhouse gas emissions to increase economic resilience.

Keywords: economic fitness, green finance, renewable energy growth, GHGs emission, diversified and complex goods

Introduction

The severe shift in the worldwide climate caused by increased greenhouse gas (GHG) emissions has presented various challenges to the survival of all species on Earth [1]. Humans have achieved many advances in several industries during the last century that have increased the amount of GHG emissions to levels not seen in the previous several years. Because of huge GHG emissions, the temperature has increased by 1.9 degrees Fahrenheit since 1880. Similarly, water levels have risen by 178 mm in the last century, while CO2 levels

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in the atmosphere have risen to 413 ppm, the highest in 650,000 years [2]. Even with a significant reduction in global emissions, the long-term effects of GHGs will be difficult for future generations. In this regard, the Paris Agreement of 2016 imposed specific constraints on all nations to reduce their carbon emissions to a bare minimum. Carbon emissions and GHGs have sparked widespread alarm among scientists around the world. Energy consumption is one of the primary causes of GHG emissions worldwide [3]. Thus, all governments must consider policies and strategies to adapt to climate change and reduce GHG emissions [4]. The concept of the circular economy has garnered increased attention in recent times, as evidenced by the endeavors of several leading global economies to integrate its tenets into their sustainable development agendas [5]. The circular economy is a revolutionary concept centered around the minimization of resource consumption and waste while fostering economic efficiency and environmental sustainability. This progressive idea includes maintaining the value and utility of products, materials, and components in separate cycles. Moreover, it involves decoupling economic development from the consumption of resources. The circular economy is gaining global importance as awareness grows regarding the necessity of changing production and consumption processes to mitigate the negative environmental effects and promote the sustainable utilization of resources [6]. The circular economy demands innovative solutions and modifications in the existing business framework to reduce the amount of unused economic resources and foster innovation [7]. It provides reliable solutions for sustainable prosperity that increase resource use efficiency and improve the environment [8]. The concept of "circular economy" is rooted in a trans-disciplinary discourse that seeks to attain circularity in natural resources' management. The implementation of policies is crucial to promoting innovative practices throughout the material life cycle. This presents a significant challenge for both the public and private sectors, which must leverage available technologies to effectively mitigate environmental impacts [9, 10].

Moreover, there is also an increase in enthusiasm for academic research, as well as research performed by practitioners and businesses interested in exploring or using the circular economy. Renewable energy (RE) is one approach that might boost the proclivity for a circular economy in the context of the sustainability of economic development processes. In advancing the circular economy, RE plays a crucial role and provides environmentally friendly alternatives to conventional sources of energy [11]. With their greater energy efficiency and low negative impacts on the environment, RE technologies seamlessly align with the principles of the circular economy. By using RE in the production process, industries can significantly lower their carbon footprints, contribute to a more responsible use of resources, and promote sustainable and eco-friendly approaches [12]. Additionally, integrating the RE into circular systems supports the localized and decentralized production of energy, which decreases the dependency on long-distance transportation [13]. Similarly, the restorative nature of the RE impeccably aligns with the circular economy's goals of replenishing and restoring energy sources over time. RE is positively associated with factors including cooling degree days and adjusted savings, reducing forest depletion. Moreover, RE reduces the net emissions of GHG and the average drought index [14]. One key aspect associated with community RE is that it contributes to achieving energy autonomy, sustainable development of rural areas, and promoting the circular economy in the energy sector [15]. Within the circular economy framework, RE positively affects the green economy. Therefore, the RE has the potential to promote sustainable development, making it an important component of the circular economy. RE and economic fitness (EFI) are commonly linked with a favorable correlation to the mitigation of GHG emissions and the decrease in temperature [16, 17].

RE is not a new idea; in fact, it has been around for decades. However, it has recently gained significant worldwide momentum due to worries about energy security and environmental sustainability. GHG emissions are a major environmental concern, and RE has been shown to be a cleaner and safer alternative to fossil fuels [18, 19]. The ability of nations to achieve energy independence is bolstered by RE since it lessens their need to import fuel. When compared to other energy sources, RE is very inexpensive for society as a whole [3]. The promotion of a green economy (GE) has become a widely accepted perspective in both societal and global prosperity, with the aim of enhancing and safeguarding ecological environments [20]. The notion of a green economy has been advocated as a novel approach to enhancing people's welfare while mitigating ecological hazards [21]. GE is a dynamic economic approach that promotes sustainable development and the efficient use of economic resources. It also integrates economic, social, and environmental aspects [22]. It aims to minimize the negative impacts on the environment by protecting biodiversity, conserving water resources, and adopting efficient waste management strategies [23] (Abdullah et al., 2017). This transformative approach includes effective use of natural resources, conservation and enhancement of natural assets, preserving biodiversity, reducing emissions and environmental pollution, generating employment opportunities, and fostering economic growth [24-26]. Moreover, GE seeks to elevate the quality of life, increase accessibility to basic social services, improve societal well-being while striving for greater equity, and decrease income disparities. Thus, the GE encompasses improvements in water and waste management, the development of eco-friendly transportation, the adoption of organic farming, the adoption of renewable energy sources, the promotion of energy-efficient housing, and the preservation and effective administration of ecosystems.

The enhancement of natural capital, including fisheries, agriculture, forest reserves, and water resources, represents two pivotal investment domains within the context of a green economy [27] and the promotion of resource conservation and efficiency in energy use, which involves the implementation of environmental technology in manufacturing, buildings, renewable energy, transportation, waste management, and tourism, as highlighted by Sahana et al. [28]. The decisions made by governments regarding investments play a crucial role in shaping the future of economies [29]. Therefore, it is reasonable to place significant emphasis on investments. According to Iqbal et al. [30], investment decisions exhibit a preference for certain types of infrastructure, manufacturing, or technology, thereby imposing constraints on potential options in the future. Consequently, it is understood that the process of economic transformation involves decision-making among different developmental trajectories, which is a complex undertaking due to the enormity of the obstacles and the requisite modifications. Investments are a crucial component of any economic strategy. However, the normative green economy vision requires a combination of private and public investments to effectively guide the economy towards more sustainable and equitable practices [31]. Therefore, it is acknowledged that these investments necessitate specific public expenditures, policy modifications, and regulatory adjustments, underscoring the significance of governmental involvement.

Governments worldwide have increasingly focused on research and development investments in RE, commonly referred to as green financing (GF), as a means of effectively mitigating GHGs. A GF is a type of financial investment that is specifically aimed at promoting environmental conservation [32]. It has been found to be effective in mitigating environmental issues such as GHG emissions as it considers both the environmental and economic factors of individual countries. The measurements offer significant advantages to key stakeholders as they furnish them with relevant and prompt information on environmental concerns [33]. The GF industry is experiencing rapid growth worldwide, resulting in significant changes to the financial system [34]. The implementation of green economic development has become imperative in order to address the interplay between natural resources, economic expansion, and the environment. The utilization of green financing has emerged as a potent instrument for facilitating low-carbon industrialization and the development of a green economy worldwide.

The concept of "economic fitness" refers to the capacity of an economy to produce a diverse array of intricate commodities. This constitutes a significant component of economic expansion and macroeconomic rivalry. Felipe et al. [35] asserted that the exportation of a diverse array of intricate commodities constitutes a crucial component of a nation's economic expansion and advancement. The discourse revolved around the nation's enduring expansion and advancement as a progression of structural transformation and manufacturing. This implies that nations are required to transition from engaging in activities with low productivity levels to those with higher productivity levels with minimum environmental hazards (CO_2 and GHG emissions). Over the course of the foreseeable future, the productivity growth of organizations is expected to decelerate if they fail to adjust to shifts in consumer demand or safeguard themselves against the unavoidable obsolescence of their workers' competencies. According to the source [36], in the absence of allocating resources to organizations with the highest potential for rapid productivity growth through the implementation of advanced technology and practices, the mean aggregate productivity of all organizations is expected to decrease. Thus, the expansion of human capital, advancements in technology, investment, and green organizational activities are all factors that contribute to sustained productivity growth over an extended period. Furthermore, it necessitates a conducive milieu for development, encompassing establishments that foster progress and a robust economy at large. The impact of various factors on the enhancement of productivity has undergone changes over a period of time. In recent times, factors such as economic fitness have gained significance alongside innovation, cross-border technology transfer, and expertise in eco-friendly production [37]. Hence, the primary catalyst for green economic development is the shift towards intricate and refined commodities through structural transformation. The trajectory of a nation's development is contingent upon the acquisition of requisite proficiencies that facilitate the creation of multifarious, intricate, and refined eco-friendly commodities [17]. In a nutshell, competitive and diversified production and GF are necessary to achieve carbon neutrality levels.

As per the previously mentioned corpus of literature, an unresolved association exists between RE growth and GHG emissions and GF, globally competitive and diversified production ability, and GDP. Despite the growing recognition of the important role that GF and globally competitive and diversified production ability (EFI) play in promoting the global economy toward sustainability, there is still a significant gap in research when it comes to comprehending their individual and synergistic impact on renewable energy growth and emission reduction. Generally, the role of GF in supporting RE initiatives exists in the literature, but there remains a lack of exploration of the role of GF in the presence of globally competitive and diversified production abilities in RE energy growth and emission reduction. Similarly, discourse on globally competitive and diversified production revolves around its economic advantages, neglecting a deep understanding of globally competitive and diversified production's implications for mitigating emissions. This gap in the literature regarding the environmental consequences of globally competitive and diversified production may impede a comprehensive understanding of how it can contribute to overall sustainable objectives. Moreover, the existing literature lacks integration of critical dimensions like

GF and EFI and their synergies in the development of RE and the reduction of emissions. Therefore, the present research makes a valuable contribution to the existing body of literature by examining the unresolved association among the aforementioned variables with the objective of devising efficacious and consensus-driven policy measures targeted at mitigating GHG emissions. Moreover, the existing literature lacks a comprehensive analysis of the contributory variables to GHG emissions. The present study aims to fill the gaps in the existing literature and provide clear policy implications for environmental sustainability.

Review of Literature

Numerous possible contributors to GHG emissions have been highlighted in the literature, including RE [38], economic growth [39], and gross value chains [38]. This research examines the synergistic influence of GF and globally competitive and diversified production ability (economic fitness) on RE growth (REG) and GHG emissions in the context of economic growth, effective governance, regulatory quality, human capital, and economic risk in light of the significance of RE in reducing the environmental effects of energy use. Modeling the relationship between energy use and CO2 emissions globally, such as [40, 41], has been a particularly active subject of study, but a scarce amount of literature is available on the impact of GF and EFI on REG and GHG emissions. Considering the pivotal significance of renewable energy (RE) in fulfilling global energy demands in the future, it is surprising that so little study has been conducted on it.

The study conducted by Shafiei and Salim [42] aimed to examine the factors that are related to environmental quality in countries that are members of the Organization for Economic Co-operation and Development (OECD). Based on empirical evidence, it can be inferred that, in the long run, the consumption of non-renewable energy sources has a noteworthy and positive effect on greenhouse gas emissions. However, the use of renewable energy sources leads to a decrease in carbon dioxide emissions. Dong et al. [43] conducted an empirical investigation to explore the correlation between GHG emissions, RE consumption, and economic growth across 120 nations. The findings of the research suggest that RE consumption has a limited yet detrimental impact on the release of GHG emissions. The causal relationships among the components exhibit inconsistencies in directionality. The impact of RE consumption on CO2 emissions varies significantly across income-based subpanels. This holds particularly true when contemplating the manifold direct and indirect pathways of influence that subsist between the two.

Subsequently, scholars have redirected their attention from RE consumption to the research and development of RE sources. They contend that investing in RE research and development is the most effective means of reducing greenhouse gas emissions [33, 44]. In their study, Tran [45] examines the relationship between GF and emissions of carbon dioxide in Vietnam. The study reveals that GF has a negative effect on emissions in the country. Mohsin et al. [46] developed a GF index and posited that this index can effectively mitigate environmental issues, such as carbon emissions. The authors contend that the GFI is a valuable tool as it incorporates both ecological and economic factors specific to each country. The measurements offer significant advantages to key stakeholders as they furnish them with relevant and prompt intelligence on environmental concerns. According to Dong et al. [43], the role of GF in alleviating energy poverty is significant. Gholipour et al. [47] reported that the implementation of GF has significantly reduced the emission of CO_2 within the industrial sector. The correlation between GF and CO2 emissions has been investigated in relation to particular industries. Scholars have investigated the correlation between GF and emissions of CO_2 in both the industrial [47] and agricultural sectors [48]. The findings suggest that GF has an adverse effect on emissions of CO_2.

The literature has also investigated the correlation between human capital and greenhouse gas (GHG) emissions. Khan et al. [49] found that human capital plays a complementary role in conjunction with other factors in reducing the emission of CO_2. Wang and Xu [50] conducted a study that utilized global data to observe the impact of human capital on ecological degradation. Through the use of sophisticated analytical methodologies, the authors have determined that the implementation of human capital has the potential to mitigate CO2 emissions. Bayar et al. [51] examine the effect of human consumption on environmental deterioration in specific European Union economies. The application of the autoregressive distributed lag (ARDL) approach reveals that human capital exerts a positive influence on the levels of CO2 emissions in European Union (EU) member states. The principal factor contributing to the favorable influence of human capital on CO2 emissions is the correlation between human capital and income growth among the populace, resulting in increased consumer demand for goods and services.

Similarly, the GDP of the countries is also found to be one of the most influential factors in RE growth worldwide [52-54]. According to these studies, GDP growth is positively associated with RE growth worldwide. The literature regarding the impact of economic fitness (competitive and diversified production ability of countries) and government effectiveness on RE growth and GHG emissions is non-existent.

As per the previously mentioned corpus of literature, there exists an unstable association between greenhouse gas (GHG) emissions and GF, economic risk, GDP, and human capital. Therefore, this research makes a valuable contribution to the current body of literature by examining the unresolved synergistic effect of GF and EFI variables in order to develop efficient and widely accepted policy measures aimed at reducing greenhouse gas emissions. Moreover, the existing literature lacks a comprehensive analysis of the collective impact of the above-mentioned contributing variables on emissions of greenhouse gases. Consequently, the objective of the present study is to endeavor to rectify the extant deficiencies in the corpus of scholarly works, thereby facilitating the provision of unequivocal policy recommendations for the promotion of sustainable development.

Materials and Methods

Hypothesis Development

The present research investigates the influence of green finance (GF), globally competitive and diversified production ability-economic fitness index (EFI) in the presence of economic growth (GDP), economic risk (ERI), effective governance (GEF), regulatory quality (RQL), and human capital (HCI), on greenhouse gas (GHG) emissions in the leading economies of the world. The research employs the economic fitness index (EFI) and GF as fundamental variables within the framework of the model that assesses greenhouse gas (GHG-En) emissions originating from energy. Green finance (GF) is a type of financial investment that is specifically aimed at promoting environmental conservation [32]. It has been found to be effective in mitigating environmental issues such as GHG emissions as it considers both the environmental and economic factors of individual countries. The measurements offer significant advantages to key stakeholders as they furnish them with relevant and prompt intelligence on environmental concerns [55]. The consensus within the current body of literature affirms the positive impact of GF practices on the reduction of greenhouse gas (GHG) emissions. GF prioritizes investments in environmentally sustainable industries and encourages businesses to develop innovative, energy-efficient technologies, such as those related to renewable energy. GF has a positive impact on the environmental outcome, as it can promote sustainable development by reducing pollution emissions [56]. By implementing the GF mechanism in crucial sectors of the economy, like construction and transportation, clean energy production may reduce emissions, lower waste, and protect biodiversity habitats [57]. Moreover, GF can effectively tackle non-point source pollution by adopting green technologies and facilitating agricultural scaling [58]. Thus, this research anticipates a favorable influence of GF on the reduction of greenhouse gas emissions (hypothesis 1). Similarly, the GF also boosts the consumption of renewable energy, named henceforth "renewable energy growth (REG) (Hypothesis 1a).

Hence, the advancement in the structure of products towards greater complexity and sophistication serves as the main catalyst for the progress of the economy. The acquisition of necessary skills that enable the creation of intricate, multifaceted, and complex products defines the trajectory of an economy's development. The Economic Fitness Index (EFI) is a metric that characterizes a nation's capacity and proficiency in generating a wide range of complicated goods in order to effectively contend in an internationalized marketing environment. The inevitability of diversifying the range of export products is rooted in various economic factors. Diversified exports can be defined as a strategy aimed at reducing the potential risks associated with international trade, as noted by Bertinelli et al. [59]. Hence, a nation's capacity to produce a wide range of goods in significant quantities is a crucial factor in achieving substantial economic growth. The economic fitness of countries is determined by their varying capabilities, which in turn affect their ability to produce a diverse and intricate range of goods. As per Nan et al. [17], a nation's capacity to produce an extensive diversity of goods in significant quantities is a key driver of economic growth. The literature extensively covers the positive impact of diversification on environmental quality, which results in a reduction of greenhouse gas emissions as the diversity of products increases [60, 61]. Fareed et al. [62] have reported that in Indonesia, there has been a notable increase in capability factor due to product diversification and RE consumption, which has consequently led to an improvement in environmental quality. It was anticipated that the implementation of EFI would have a positive impact on the subject matter (reducing GHG-EN) (Hypothesis 2). Moreover, it is also hypothesized that the EFI will also enhance the REG (Hypothesis 2a).

Moreover, the current study considers the combined effect of GF and EFI on the GHG emissions (hypothesis 3) and growth of renewable energy (hypothesis 4) of the sampled countries. GF and EFI are hypothesized to synergistically affect GHG emissions and REG. GF serves as a catalyst for promoting the adoption of RE infrastructure by providing financial support for sustainable projects. EFI contributes to the reduction of GHG emissions by increasing efficiency and promoting the adoption of cleaner technologies. The real synergy lies in the way GF directs investment into economically competitive sectors, accelerating the transition to RE and paving the way for eco-friendly technologies. This synergy creates a positive feedback loop where GF facilitates economic growth, amplifies international competitiveness, and fosters the widespread implementation of cleaner technologies. Therefore, the synergies between GF and EFI are expected to boost the REG while simultaneously curbing GHG emissions by enhancing efficiency and promoting the universal adoption of sustainable practices. For this purpose, we have taken the interaction effect of GF and EFI as the independent variable in the empirical model. We supposed the positive and large combined effect of GF and EFI on the GHG-EN and REG.

The GHG-En model incorporates GDP as a significant explanatory variable. The correlation between the growth of the economy and the consumption of energy as well as the emission of GHGs has been proposed. The utilization of energy has significantly contributed to the growth and development of the economies of the OECD nations. It is expected that the gross domestic product (GDP) will have a positive impact on greenhouse gas emissions (GHG-En) in the member countries of the Organization for Economic Co-operation and Development (OECD). The research incorporates the utilization of human capital (HC) as an additional prospective determinant of greenhouse gas emissions. The current body of literature presents varying outcomes regarding the relationship between HCI and CO2 emissions. Various studies have demonstrated the efficacy of HC in mitigating CO2 emissions [50, 63-65]. In contrast, Bayar et al. [51] contend that the utilization of HC leads to a rise in carbon dioxide emissions. As per the findings of Bayar et al. [51], it is anticipated that there will be a favorable influence of human capital (HC) on greenhouse gas (GHG) emissions. The underlying economic mechanism responsible for the favorable influence of the human-capital index (HCI) on greenhouse gas emissions (GHG-En) is predicated on the notion that advancements in HCI bolster economic expansion, thereby leading to heightened energy consumption and subsequent gas emissions. Therefore, it is contended that the accrual of human capital results in heightened productivity, subsequently engendering a rise in national income. Notwithstanding this fact, the national income is heavily dependent on fuel combustion, thereby exacerbating the emission of greenhouse gases. The model of greenhouse gas (GHG) emissions utilized in this study incorporates economic risk (ERI), as per the methodology outlined by Fu et al. [66]. The extant body of literature has regarded economic risk as a significant determinant of greenhouse gas emissions. The earlier studies have reported a favorable influence of energy efficiency measures on reducing carbon dioxide emissions [67, 68]. Adedoyin and Zakari [69] contend that the mitigation of CO2 is facilitated by economic risk. According to the authors' argument, the presence of economic risk has a negative impact on the expansion of production, leading to a decline in the levels of CO2 emissions.

One of the components of institutional quality is the effectiveness of the government, which is responsible for creating a business environment that is conducive to profitability and free from political interference. Additionally, this factor is indicative of the quality of services that are provided to the citizens of a given country. The effectiveness of the government is a desirable tool for regulating both corruption and the informal economy [70]. According to scholarly research, the efficacy of governmental institutions has a positive impact on economic expansion [71], as well as fostering innovative practices within firms pertaining to their products, technologies, and management strategies [72]. Through targeted mechanisms, GEF has a profound impact on both GHG emission reduction and promoting the REG. Initially, robust and well-designed regulatory frameworks are very important for reducing GHG emissions. These frameworks encompass the strict emission limits and mandates that are enforced across the various industries. Moreover, market-based instruments such as emission trading systems or carbon pricing not only incentivize businesses to reduce their emissions [73], but also establish a systematic approach to meet emission reduction targets. Similarly, in the realm of REG, the GEF is also very important in shaping regulatory policies and incentives for progress. The government can enforce supportive measures, including tax credits, feed-in tariffs, and subsidies, to create an environment that makes investment in RE projects economically feasible [74]. Moreover, the GEF provides a stable foundation for investors and businesses, promoting long-term planning and development in the RE sector. Thus, GEF is essential in achieving sustainability goals and transitioning towards a more resilient and low-carbon global energy landscape by aligning government strategies with REG and GHG emission reduction. Therefore, it has been assumed that an effective government may assist in reducing GHG emissions and increasing renewable energy growth in the country.

Regulatory reforms that enhance competition are crucial for the dissemination and advancement of novel technologies. In order to enhance the level of innovation within the nation, it is imperative that regulations across all sectors are fully adaptable to changes in technical, social, and economic circumstances. The development of novel renewable energy technologies necessitates substantial financial investments and favorable governmental policies, both of which are lacking in many developing nations, resulting in a sluggish rate of dissemination [75]. As per diffusion theory, the effective diffusion of technological innovation is significantly influenced by government policies. This highlights the crucial role played by government policies in this regard. The implementation of specific governmental policies has the potential to decrease the consumption of fossil fuels by incentivizing the preference for innovative alternatives. The dynamic and mutual interface between regulation and innovation is attributed to the significant impact of regulatory quality as a stimulus for further innovation [76]. In addition, a robust regulatory framework has the potential to enhance the relationship between innovation and renewables by providing consistent and reliable policy signals over the long term. This can foster confidence in prospective adopters and innovators of environmentally sustainable concepts, thereby encouraging the necessary investments. long-term viability of its resources in order to ensure continued growth and development. A conducive business environment can enable domestic firms and investors to achieve their objectives. Therefore, it is imperative for domestic economic agents to implement sustainable practices aimed at mitigating greenhouse gas emissions and promoting the uptake of renewable energy sources. The aforementioned benefits can only be attained through the establishment of a continuous flow of innovative practices by corporations. The conduct of economic actors within a nation is contingent upon the presence of favorable institutional circumstances. The assurance of an economic actor increases with the establishment of well-defined property rights, adherence to regulations by all parties, and the successful implementation of efficient policies [17]. Thus, it is imperative to ensure regulatory quality in order to facilitate the uptake of renewable energy sources and mitigate greenhouse gas emissions within the nation. Thus, it has been hypothesized that the regulatory quality that entails sound policy implementation and regulation may reduce GHG emissions and increase renewable energy growth.

Econometric Model Construction

Drawing upon the theoretical analysis presented above, this paper proceeds to construct econometric models through a series of steps and subsequently conducts an empirical analysis. In order to corroborate Hypothesis 1, a two-fold procedure is required. Initially, this study investigates the relationship between greenhouse gas emissions (GHG-En) and green finance (GF) without taking into account the impact of economic fitness (EFI). An econometric model (Model 1.) is developed for this purpose. Subsequently, additional control variables are incorporated to construct another econometric model (Model 2.).

$$GHG - En_{it} = \beta_o + \beta_1 GF_{it} + \mu_{it} \quad \text{Model 1.}$$

$$GHG - En_{it} = \beta_o + \beta_1 GF_{it} + \beta_2 GDP_{it} + B_3 GEF_{it} + \beta_4 RQL_{it} + \beta_5 HCI_{it} + \beta_6 ERI_{it} + \mu_{it} \quad \text{Model 2.}$$

In order to corroborate Hypothesis 1a, a two-fold procedure is required. Initially, this study explores the association between RE growth (REG) and green finance (GF) without taking into account the impact of economic fitness (EFI). An econometric model (Model 1a.) is developed for this purpose. Subsequently, additional control variables are incorporated to construct another econometric model (Model 2a.).

$$REG_{it} = \beta_o + \beta_1 GF_{it} + \mu_{it} \quad \text{Model 1a.}$$

$$REG_{it} = \beta_o + \beta_1 GF_{it} + \beta_2 GDP_{it} + B_3 GEF_{it} + \beta_4 RQL_{it} + \beta_5 HCI_{it} + \beta_6 ERI_{it} + \mu_{it} \quad \text{Model 2a.}$$

Subsequently, taking into account the capacity of economies to produce complex and diverse commodities to contend in the global market, which is commonly referred to as the economic fitness of economies (EFI), an examination of the influence of EFI on GHG_EN is conducted (Hypothesis 2). This is accomplished by developing an econometric model (Model 3.) and subsequently incorporating pertinent control variables to establish another econometric model (Model 4.).

$$GHG - En_{it} = \beta_o + \beta_1 EFI_{it} + \mu_{it} \quad \text{Model 3.}$$

$$GHG - En_{it} = \beta_o + \beta_1 EFI_{it} + \beta_2 GDP_{it} + B_3 GEF_{it} + \beta_4 RQL_{it} + \beta_5 HCI_{it} + \beta_6 ERI_{it} + \mu_{it} \quad \text{Model 4.}$$

To substantiate Hypothesis 2a, the present study aims to explore the correlation between the growth of renewable energy (REG) and economic fitness (EFI), while disregarding the influence of GF. A model with econometric characteristics, specifically Model 3a., has been formulated for this objective. Following this, supplementary control variables are integrated to formulate an alternative econometric model, denoted as Model 4a.

$$REG_{it} = \beta_o + \beta_1 EFI_{it} + \mu_{it} \quad \text{Model 3a.}$$

$$REG_{it} = \beta_o + \beta_1 EFI_{it} + \beta_2 GDP_{it} + B_3 GEF_{it} + \beta_4 RQL_{it} + \beta_5 HCI_{it} + \beta_6 ERI_{it} + \mu_{it} \quad \text{Model 4a.}$$

In order to test Hypothesis 3, additional research was conducted to assess the potential effect of EFI on the association between GF and GHG-En. This was achieved by increasing the interaction between GF and EFI, constructing an econometric model (Model 5.), and introducing relevant control factors to build a statistical model (Model 6.).

$$GHG - En_{it} = \beta_o + \beta_1 GF_{it} + \beta_2 EFI_{it} + \beta_3 GF_{it} * EFI_{it} + \mu_{it} \quad \text{Model 5.}$$

$$GHG - En_{it} = \beta_o + \beta_1 GF_{it} + \beta_2 EFI_{it} + \beta_3 GF_{it} * EFI_{it} + \beta_4 GDP_{it} + B_5 GEF_{it} + \beta_6 RQL_{it} + \beta_7 HCI_{it} + \beta_8 ERI_{it} + \mu_{it} \quad \text{Model 6.}$$

To investigate Hypothesis 4, supplementary research was carried out to investigate the possible impact of EFI on the association between GF and REG. The aforementioned outcome was attained through the augmentation of the interplay between GF and EFI, the development of an econometric model (Model 5a.), and the incorporation of pertinent control variables to establish a statistical model (Model 6a.).

$$REG = \beta_o + \beta_1 GF_{it} + \beta_2 EFI_{it} + \beta_3 GF_{it} * EFI_{it} + \mu_{it} \quad \text{Model 5a.}$$

$$REG_{it} = \beta_o + \beta_1 GF_{it} + \beta_2 EFI_{it} + \beta_3 GF_{it} * EFI_{it} + \beta_4 GDP_{it} + B_5 GEF_{it} + \beta_6 RQL_{it} + \beta_7 HCI_{it} + \beta_8 ERI_{it} + \mu_{it} \quad \text{Model 6a.}$$

Empirical Models

Initially, the existence of a unit root in the data was verified. Subsequently, cointegration tests were conducted, and the long-term coefficients were assessed using the FMOLS. Equation (1) specifies that the time series V_{it} conforms to an autoregressive (AR) process. Equation (2) outlines the null hypothesis for a homogeneous panel unit root test, whereas Equation (3) presents the null hypothesis for a panel heterogeneous unit root test.

$$\Delta V_{it} = \gamma_i V_{it-1} + \emptyset_{it} \quad (1)$$

$$H_0 : \gamma_i = \gamma_0 = 0 \; for \; all \; i, whereas \; H_A : \gamma_i = \gamma_A \neq \gamma_0 \quad (2)$$

$$H_0 : \gamma_i = \gamma_0 = 0 \; for \; all \; i, \quad as \; H_A : \gamma_A \neq \gamma_0 \quad (3)$$

Equation 2's homogeneity hypothesis pertains to the uniform cross-sectional nature, as highlighted by Breitung [77] and Levine et al. [78], that is present across all members. Equation 3 postulates the absence of identical cross-sectionality [79, 80]. The stationarity of the time series (Z_{it}) was determined across the application of both heterogeneous and homogeneous unit roots tests. Thus, the subsequent equation illustrates the panel regression.

$$V_{it} = \forall_i \beta_i Z'_{it} + \partial_{it} \quad (4)$$

The k x 1 column vector is denoted by V, while the k x 1 constant's vector is represented by $\forall_i$. The n x 1 vector of slope coefficients is denoted by beta, and Z'_{it} is used to describe the vector of explanatory variables. Additionally, ∂_{it} represents the residual term's vector. Consequently, the residual term for a stationary time series must follow the I (0) process for the i^{th} segment at the interval "t". Correspondingly, the confirmation of cointegration is established when the residual term adheres to the I (1) process [81, 82]. The analysis of cointegration was conducted using both homogeneous ($\beta_i = \beta_0$) and heterogeneous ($\beta_i \neq \beta_0$) variation structures. Equation (5) was utilized to examine cointegration [82, 83].

$$\partial_{it} = u\partial_{it-1} + \eta_{it} \quad (5)$$

Equation (6) illustrates the concept of homogeneous panel cointegration, and Equation (7) illustrates the null hypothesis of heterogeneous panel cointegration.

$$H_0 : u_i = u_0 = 1 \, for \, all \, I, whereas \, H_A ; \quad u_i = u_A < 1 \neq u_0 \quad (6)$$

$$H_0 : u_i = u_0 = 1 \, for \, all \, I, whereas \, H_A ; \quad u_i < 1 \neq u_0 \quad (7)$$

Model-1 Fully Modified Ordinary Least Squares

Following the cointegration test, the FMOLS technique was applied in order to provide an estimate of the long-term panel coefficient. In order to accomplish this goal, the covariance matrix was deconstructed using Equation (8):

$$\rho = \sum_{j=-\infty}^{\infty} E\,(\omega_{ij}\omega'_{io}) = \begin{bmatrix} \rho_\eta & \rho_{\eta\epsilon} \\ \rho_{\epsilon\eta} & \rho_\epsilon \end{bmatrix} \quad (8)$$

Where, $\omega_{it} = (\eta_{it}, \epsilon'_{it})'$. In addition, the homogeneous covariance matrix is shown in equation 9.

$$\Omega = \sum_{j=0}^{\infty} E\,(\omega_{ij}\omega'_{io}) = \begin{bmatrix} \Omega_\eta & \Omega_{\eta\epsilon} \\ \Omega_{\epsilon\eta} & \Omega_\epsilon \end{bmatrix} \quad (9)$$

Equations 10 and 11 outline the OLS ($\hat{\beta}_{OLS}$) and FMOLS ($\hat{\beta}_{FMOLS}$) methods [84]. In order to address the issues of endogeneity and serial correlation, it is common practice to condition the OLS estimate on a non-zero mean normal distribution, while the FMOLS estimate is conditioned on an asymptotically non-zero mean normal distribution, as noted in reference [85].

$$\hat{\beta}_{OLS} = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}(Z_{it} - \bar{Z}_i)^2\right)^{-1} \left(\sum_{i=1}^{N}\sum_{t=1}^{T}(Z_{it} - Z_i)\,(V_{it} - V_i)\right) \quad (10)$$

$$\hat{\beta}_{FMOLS} = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}(Z_{it} - \bar{Z}_i)^2\right)^{-1} \left(\sum_{i=1}^{N}\sum_{t=1}^{T}(Z_{it} - \bar{Z}_i)\,(V^*_{it} - T\Omega_{\epsilon\eta})\right) \quad (11)$$

Where $V^*_{it} = V_{it} - \rho^*_{\eta\epsilon}\, \rho_\epsilon\, \epsilon_{it}$ and $\Omega^*_{\eta\epsilon} = \Omega^*_{\eta\epsilon} - \Omega_\epsilon\, \rho_\epsilon^{-1}\, \Omega_{\epsilon\eta}$

Model-2 Generalized Method of Moments

The Generalized Method of Moments (GMM) is a highly prevalent econometric analysis technique that has gained widespread adoption across the world. Hansen [86] put out this idea. This approach facilitates the visualization of the anticipated moments of population distribution in contrast to the moments of the sample. It addresses autocorrelation as well as a number of different variations [87]. Equation 12 outlines the overall purpose of the GMM technique, which is to determine the parameters that are unidentified through determining the sample means of moment functions [88].

$$E[A_i'\,\eta_i] = 0 \quad (12)$$

A one-step GMM approach is utilized to estimate the most effective linear combination of moments [89, 90]. The relative weight matrix structures of the predicted aspects in a one-step GMM are calculated independently via the weighting matrices w [91, 92].

$$w = \begin{bmatrix} w_d & 0 \\ 0 & w_1 \end{bmatrix} \quad (13)$$

The one-step estimator proposed by Arellano and Bond [93] utilized an identity matrix as a weighing matrix. On the other hand, the one-step GMM approach employed both the weighting matrix (as specified in equation 15) and the estimator specified in equation 16. The most effective estimator for GMM is determined as the independent and identically distributed (iid) mean value of $[0, \sigma^2 I_t]$.

$$w_N = \left[\sum_i A_i' A_i\right]^{-1} = [A'A]^{-1} \quad (14)$$

$$\hat{\beta}_{OLS} = [Z'A\,(w)^{-1}\,A'Z]^{-1}\,Z'A\,(w)^{-1}\,A'v \quad (15)$$

Model-3 Quantile Regression

The OLS regression method is highly reliant on its underlying assumptions. If any of the aforementioned presumptions are not met, the Ordinary Least Squares (OLS) method may not produce estimates that are optimal [94]. In the context of a heterogeneity issue, the ordinary least squares (OLS) method may not be capable of accurately estimating coefficients that are both effective and logical. The utilization of a regression model in this scenario can account for the quantile and heterogeneity structures inherent in the data. Hence, it can be inferred that in such situations, the most suitable alternative is quantile regression (QR) [95, 96]. The superiority of the model over OLS regression lies in the fact that it obviates the need to make any assumptions regarding the dispersion of the error terms that are anticipated by the model [97]. The Ordinary Least Squares (OLS) model makes predictions by incorporating the anticipated average value of the dependent variable. QR is a statistical method that utilizes the conditional median to generate predictions. According to Ong et al. [98], quantile regression (QR) determines the coefficient by examining various quantiles, such as the 25th, 50th, and 75th quantiles, of the response variable.

The QR was introduced by Koenker and Bassett in 1978 [99]. In 2001, Koenker and Hallock [100] introduced enhancements to the aforementioned method. The utilization of QR does not necessitate the adherence of variables to the normal distribution. Thus, the specified model takes the form of a linear regression equation.

$$a_i = \beta_o + \beta_1 v_{i1} + \cdots + \beta_p v_{ip} \quad i = 1, \ldots, n \tag{16}$$

The equation 16 specifies the number of parameters that require estimation, while i denotes the total number of data points. Equation 16 provides the basis for specifying the QR in equation 17, which is expressed for the Tth quantile. Thus, it can be inferred that the coefficient is reliant on the quantile [101]. Equation 18 presents the ultimate QR model.

$$Q_T(a_i) = \beta_o(T) + \beta_1 (T) v_{i1} + \cdots + \beta_p (T) v_{ip} \quad i = 1, \ldots, n \tag{17}$$

$$Q_T \mathrm{a}(T | a_{i,t-1,} a_{it}) = \partial_i + \nu(T) a_{i,t-1} + x_{it}^T \beta (T) \quad i = 1, \ldots, n. \quad t = 1, \ldots T_i \tag{18}$$

Where; a_{it} represents the estimated outcome, while $a_{i,t-1}$ denotes the lag value of a_{it}. The exogenous variables are represented by x_{it}, and the N x1 vector of intercepts is denoted by $\partial_i = (\partial_1, \ldots, \partial_N)$. The Tth quantile is a determining factor in the relationship between the variables $(a_{i,t-1})$ and (x_{it}).

Results

Table 1 presents a comprehensive overview of all variables within the panel. The assessment of variable normality was conducted through the utilization of the JB-test and the computation of kurtosis and skewness values. The findings of the JB-test described that the variables did not follow a normal distribution. Under these conditions, the soundness of the t-test and F-test is supported by the extensive sample size; this is explained by OLS's asymptotic normality. According to Machado and Silva [102], utilizing quantile regression instead of OLS regression yields dependable estimates in cases where the variables are not distributed normally. Furthermore, it has been demonstrated that quantile regression maintains its efficacy even in the presence of significant skewness and kurtosis, as evidenced by previous research [103].

Due to the problem of heterogeneity and cross-sectional (CSD) dependence in the data, the estimation of parameters may exhibit inconsistency and bias. In order to alleviate this situation, it is imperative to conduct a cross-sectional dependency test and heterogeneity analysis. The outcomes concerning heterogeneity and cross-sectional dependency are displayed in Table 2. The panel data of the economies was found to exhibit cross-sectional dependency [104] through the utilization of two LM tests, one Pesaran scaled and the second Breusch-Pagan, and Pesaran CD is also applied. The interdependence observed could potentially be attributed to similar global factors, such as fluctuations in the costs of energy or developments in technology. The utilization of fixed and panel effects in this particular scenario may result in estimators that are both biased and unreliable. Various methods exist to address CSD. For instance, incorporating common factors or capturing their impact in panel regression can yield dependable estimators [105]. Furthermore, the utilization of the bootstrap method (with 1000 replications) can be

Table 1. Descriptive Analysis.

Variables	Mean	Med	Max.	Min.	SD	Skew-ness	Kurtosis	JB-test	p-scores
GHG-En	6.251	5.8732	6.892	5.293	0.328	1.2327	3.5782	64.987	0.000
REG	0.814	0.2665	21.535	0.974	1.945	5.1344	4.7362	36.4632	0.000
GF	1.237	1.0971	1.709	0.231	0.326	0.8936	3.7763	39.237	0.000
EFI	1.402	1.2983	3.782	1.782	0.378	2.6342	11.372	68.264	0.000
GDP	13.54	12.378	14.35	12.007	0.321	1.0032	3.2612	41.073	0.000
GEF	1.432	1.2391	1.723	-0.043	0.216	-0.0263	3.7712	35.328	0.000
RQL	1.109	1.0672	1.773	-0.321	0.278	-0.4662	3.2817	89.353	0.000
HCI	0.608	0.5723	1.398	0.321	0.228	-0.5732	2.8743	57.387	0.000
ERI	1.476	1.4563	1.732	0.893	0.068	2.98172	28.432	1314.26	0.000

Med=Median; SD=Standard Deviation

deemed appropriate for estimating and identifying potential biases in a panel estimation. Furthermore, Juhl and Lugovskky [106] have expounded that in panel estimation, the coefficients obtained are analogous for every cross-sectional unit. The aforementioned assumption is found to be in contravention with population data, thereby giving rise to the issue of type II error. This error pertains to the scenario wherein a false null hypothesis is not rejected. The outcome could potentially lead to parameters that are influenced by prejudice. We used the slop heterogeneity test proposed by the Pesaran-Yamagata test [107] to verify that the slope coefficients are consistent across the panel's cross-sectional unit. The null hypothesis has been rejected based on the test results, indicating that the slope coefficients are not uniform across the panel units.

Panel QR can address the issue of inconsistent slop heterogeneity by estimating parameters at the upper, median, and lower tails of the conditioned distribution. A test to determine whether or not the quantile slopes are equal is presented in Table 3. The coefficients of GF, EFI, GEF, HCI, and ERI exhibited significant differences between the quantiles 25th (lower) and 50th (median). The measurements of GF, EFI, GDP, GEF, RQL, and ERI exhibited significant differences at both the median (50th) and upper (75th) quantiles. As a result, the general alternate hypothesis was accepted that all coefficients are not identical.

Prior to parameter estimation, the degree of integration (I(0) or I(1)) of the variables was confirmed by employing the unit root test. For this purpose, we have applied the cointegration test. We used Hadri's unit root test [108], which was further refined by Breitung and Das [109]. This test is widely used in the data where CS-dependency exists. The unit root test proposed by Hadri [108] assumes stationarity for all panels or trends, whereas Breitung and Das [109] posit that all panels exhibit a unit root. Hadri [108] and Breitung and Das [109] provided assistance in selecting one of the available options in Stata 15, which include (i) fixed effects for panel-specific means, (ii) time trends, (iii) subtraction of CS means, and (iv) incorporation of CS dependence in the model. Bilgili et al. [105] employed a comparable unit root test. The findings in Table 4 validate that the variables exhibiting I(0) characteristics are non-stationary, whereas those displaying 1st order differences are stationary, thereby conforming to the I(1) order.

The Westerlund [110] cointegration test included CS dependency using group average (Gt, Ga) and panel (Pt, Pa) statistics. Table 5 shows that Pt's z score at 1% significance showed cointegration. Wasterlund's cointegration test [110] was reproduced 500 and 1000 times and disproved the null hypothesis of no cointegration. To test the

Table 2. Testing slope heterogeneity and cross-sectional dependency

	scores	p-value
Breusch-Pagan	6137.23	0.00
Pesaran scaled	16.893	0.00
P-CD	14.672	0.00
Measure of slope heterogeneity		
PY-D	2.68	0.01
PYA-D	6.47	0.00

PY-D= Pasaran-Yamagata Delta; PYA-D= Pasaran-Yamagata Adj. Delta

Table 3. Slope equality test at different quantile tails

		Statistic	d.f.	p-value
Wa-T		276.342	13.000	0.0000
Res.D: b(tau_h) - b(tau_k) = 0				
Qu	Vari-ables	Res.V	Std.Err.	P-value
0.25, 0.50	GF	0.015	0.003	0.000
	EFI	0.021	0.007	0.001
	GDP	-0.056	0.042	0.342
	GEF	-0.055	0.012	0.000
	RQL	0.032	0.025	0.628
	HCI	0.036	0.013	0.011
	ERI	0.028	0.011	0.00
0.50, 0.75	GF	0.025	0.002	0.000
	EFI	0.018	0.001	0.000
	GDP	-0.040	0.018	0.021
	GEF	-0.141	0.012	0.000
	RQL	0.030	0.003	0.000
	HCI	0.053	0.029	0.468
	ERI	0.043	0.011	0.000

Wa-T= Wald test; Qu = Quantiles; Res.D= Restriction Detail; Res.V= Restricted value; Std.Err. = Standard Value.

Table 4. Testing unit root in panels.

Variables	z-value	p-scores	z-value	p-scores
GHG-En	43.65	0.00	-1.77	0.651
REG	37.55	0.00	-1.43	0.440
GF	34.67	0.00	-2.15	0.342
EFI	29.46	0.00	-1.78	0.465
GDP	43.65	0.00	-2.66	0.378
GEF	27.82	0.00	-2.68	0.133
RQL	40.32	0.00	-1.56	0.783
HCI	25.18	0.00	-1.23	0.682
ERI	21.67	0.00	-2.87	0.324
GF	33.29	0.00	-2.05	0.432
EFI	20.54	0.00	-1.88	0.321

Table 5. Outcomes of Westerlund test.

Tests	Value	z- value	p-score
Gt-statistics	-3.256	-0.1.58	0.445
Ga-statistics	-2.356	7.328	1.000
Pt-statistics	-16.084	-4.955	0.0001
Pa-statistics	-4.662	2.455	0.879
VR-statistics	-4.005	---	0.0151

VR = Variance Ratio

cointegration, the current study conducted a variance ratio VR-test [110], taking into account the presence of a unit root in the residual. The alternative hypothesis predicted cointegration in certain panels, while the null hypothesis predicted none. The statistical test has verified the existence of cointegration with a significance level of 5%. Thus, the variables have a cointegrating relationship and an order of integration of one in the calculated matrix. The results of the unit root and cointegration tests indicate that it is feasible to estimate parameters using QR, GMM, and FMOLS.

Table 6 displays the GHG-En outcomes estimated via FMOLS, QR, and GMM methodologies. The findings of all models indicate that the GF, EFI, and their combined impact have a statistically significant reduction on GHG-En emissions. The GF's estimations on GHG emission (Model 6.) were obtained through the application of QR (25), QR (50), and QR (75), GMM, and FMOLS approaches, resulting in values of -0.110, -0.326, -0.119, -0.20, and -0.237, respectively. The findings demonstrate statistical significance at a 1% level of significance, thereby providing support for Hypothesis 1 and confirming the notable impact of GF in mitigating GHG-En emissions. All Models (1-6) confirm hypothesis 2, and the estimation of EFI on GHG-En from FMOLS -0.102, GMM -0.226, from QR (25), QR (50), and QR (75) -0.091, -0.177, and -0.197, respectively. The econometric model's outcomes indicate that the estimation results of the core variable are resilient. Subsequently, we proceed to incorporate the interaction term between GF and EFI into our analysis, utilizing Models 5. and 6. to explore the combined influence of GF and EFI on the mitigation of greenhouse gas emissions from energy use. The emission of GHG-En was found to be adversely impacted by several control variables, namely GDP, GEF, RQL, HCI, and ERI. Moreover, all of these variables were observed to mitigate GHG emissions across all quantiles. The study reveals that the gross domestic product (GDP) has varying effects on greenhouse gas-energy (GHG-En) emissions, as estimated by different econometric techniques. Specifically, the Fully Modified Ordinary Least Squares (FMOLS) approach yields an impact coefficient of 0.032, while the Generalized Method of Moments (GMM) approach yields a coefficient of 0.043. On the other hand, the quantile regression (QR) approach produces impact coefficients of 0.0010, 0.0012, and 0.0009 for the 25th, 50th, and 75th percentiles, respectively. The study reports the estimated impact of government effectiveness (GEF) on the outcome variable using various econometric techniques. The findings indicate that the estimated impact of GEF from FMOLS is -0.087, from GMM is -0.137, and from QR (25), QR (50), and QR (75) is -0.182, -0.191, and -0.211, respectively. The study reveals that regulatory quality (RQL) has a negative impact on the GHG-En, as evidenced by the results obtained from FMOLS (-0.0432), GMM (-0.142), QR (25) (-0.043), QR (50) (-0.052), and QR (75) (-0.069). The effects of human capital on greenhouse gas emissions, as determined through the use of Fully Modified Ordinary Least Squares (FMOLS), Generalized Method of Moments (GMM), and Quantile Regression (QR) techniques at various quantiles (25th, 50th, and

Table 6. Synergistic and individual effect of GF and EFI on GHG_En

DV: GHG-En	FMOLS					
	Coef. (Std.Err.)					
Variables	Model 1a	Model 2a	Model 3a	Model 4a	Model 5a	Model 6a
GF	-0.003 * (0.0001)	-0.012* (0.005)	--		-0.166* (0.0021)	-0.110* (0.003)
EFI	--	--	-0.231* (0.0017)	-0.167* (0.0002)	-0.189* (0.0027)	-0.102* (0.0009)
GF*EFI	--	--	--	--	-0.324* (0.0014)	-0.377* (0.0021)
GDP	--	0.016* (0.004)	--	0.0123* (0.0017)	--	0.032* (0.003)
GEF	--	-0.104* (0.0015)	--	-0.235* (0.002)	--	-0.087* (0.0043)
RQL	--	-0.002** (0.0011)	--	-0.03* (0.0015)	--	-0.0432* (0.0021)
HCI	--	-0.0773* (0.0012)	--	-0.004* (0.0009)	--	-0.225* (0.006)
ERI	--	-0.023* (0.0012)	--	-0.231* (0.0032)	--	-0.034* (0.0012)
GMM						
GF	-0.003 * (0.0006)	-0.053* (0.008)	--		-0.223* (0.001)	-0.326* (0.004)
EFI	--	--	-0.268* (0.0022)	-0.307* (0.0045)	-0.278* (0.0039)	-0.226* (0.008)
GF*EFI	--	--	--	--	-0.436* (0.0048)	-0.398* (0.0027)

GDP	--	0.143* (0.004)	--	0.112* (0.0071)	--	0.043* (0.0021)
GEF	--	-0.178* (0.0023)	--	-0.098* (0.0063)	--	-0.137* (0.0013)
RQL	--	-0.043** (0.0014)	--	-0.049* (0.0021)	--	-0.142* (0.0015)
HCI	--	-0.420* (0.0092)	--	-0.304* (0.0063)	--	-0.205* (0.0037)
ERI	--	-0.132* (0.0022)	--	-0.372* (0.0067)	--	-0.145* (0.0022)
QR (0.25)						
GF	-0.0754* (0.0030)	-0.0224* (0.0026)			-0.121* (0.0020)	-0.119* (0.0032)
EFI			-0.052* (0.0024)	-0.0111* (0.0016)	-0.089* (0.0033)	-0.091* (0.0029)
GF*EFI					-0.113* (0.0019)	-0.199* (0.0002)
GDP		0.0019* (0.0021)		0.0009* (0.00002)		0.010* (0.0011)
GEF		-0.042 (0.204)		-0.182* (0.007)		-0.182* (0.007)
RQL		-0.062* (0.0021)		-0.043* (0.001)		-0.043* (0.001)
HCI		-0.056* (0.0014)		-0.137* (0.0021)		-0.137* (0.0021)
ERI		0.0058 (0.276)		-0.101* (0.002)		-0.101* (0.002)
QR (0.50)						
GF	-0.134* (0.0040)	-0.210* (0.0061)			-0.186* (0.0022)	-0.20* (0.0007)
EFI			-0.089* (0.0011)	-0.0154* (0.0032)	-0.113* (0.0022)	-0.177* (0.0045)
GF*EFI					-0.199* (0.0029)	-0.231* (0.008)
GDP		0.0204* (0.003)		0.0017* (0.0012)		0.0012* (0.00023)
GEF		-0.242* (0.0043)		-0.201* (0.0027)		-0.191* (0.009)
RQL		-0.201* (0.0002)		-0.187* (0.0031)		-0.052* (0.004)
HCI		-0.300* (0.0031)		-0.203* (0.004)		-0.148* (0.0033)
ERI		-0.0123* (0.0007)		-0.122* (0.0006)		-0.192* (0.003)
QR (0.75)						
GF	-0.244* (0.0028)	-0.287* (0.0045)			-0.196* (0.0028)	-0.237* (0.0016)
EFI			-0.113 (0.0027)	-0.0175 (0.004)	-0.143* (0.0016)	-0.197* (0.0037)
GF*EFI					-0.207* (0.0016)	-0.291* (0.004)
GDP		0.0219* (0.003)		0.014* (0.002)		0.0009* (0.00002)
GEF		-0.242 (0.0017)		-0.288* (0.0013)		-0.211* (0.006)
RQL		-0.298* (0.003)		-0.213* (0.0029)		-0.069* (0.0032)
HCI		-0.305* (0.0041)		-0.254* (0.0031)		-0.183* (0.0031)
ERI		-0.144* (0.0027)		-0.159* (0.0021)		-0.203* (0.002)

75th), are as follows: -0.225, -0.205, -0.137, -0.148, and -0.183. Consequently, in accordance with hypothetical expectations, it was determined that all variables had a negative and significant impact, with the exception of GDP, which had a significant and positive impact on GHG emissions. Consequently, a substantial investment in green industries and incentivizing businesses to develop novel, energy-efficient technologies such as renewable energy can effectively mitigate greenhouse gas emissions resulting from energy production. Diversification of production towards complex goods to enhance global competitiveness has been found to be an effective strategy for reducing greenhouse gas emissions from energy sources. Likewise, various other factors that delineate effective governance and regulatory excellence, encompassing the proficient execution of policies and regulations within the nation, also serve to diminish greenhouse gas emissions. The human resources development process has been identified as a contributor to the emission of greenhouse gases from energy sources, with adverse effects. The adverse effect of ERI on GHG emissions can be attributed to its negative impact on output growth, which subsequently results in a reduction of GHG emissions.

The outcomes concerning the estimation of REG through FMOLS, QR, and GMM techniques are presented in Table 7. The results of all models demonstrate that each variable exerts a statistically significant influence on either the consumption of renewable energy or its growth. The analysis of the models from 1a to 6a reveals that GF and EFI have a significant influence on the expansion of renewable energy. Therefore, it can be concluded that these factors are crucial determinants of renewable energy growth. The GF's estimations on REG (Model 6.) were derived using various econometric techniques, namely FMOLS, GMM, and QR (25), QR (50), and QR (75). The resulting estimates were 0.20, 0.29, 0.030, 0.041, and 0.056, respectively. The results indicate a statistically significant relationship at a significance level of 1%, thereby corroborating Hypothesis 1a and validating the significant influence of GF on the expansion of REG. The findings from models 1a-6a support hypothesis 2a. The calculated EFI values for REG using FMOLS, GMM, QR (25), QR (50), and QR (75) are 0.125, 0.133, 0.070, 0.079, and 0.121, respectively. The results of the econometric model suggest that the estimation outcomes of the fundamental variable exhibit robustness. Following this, we proceeded to integrate the interaction term between GF

Table 7. Synergistic and individual effect of GF and EFI on REG

DV: REG	FMOLS					
	Coef. (Std.Err.)					
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
GF	0.0018 * (0.0001)	0.0022* (0.0005)	--		0.087* (0.0031)	0.20* (0.001)
EFI	--	--	0.043* (0.0005)	0.039* (0.0017)	0.141* (0.027)	0.125* (0.019)
GF*EFI	--	--	--	--	0.126** (0.058)	0.159* (0.044)
GDP	--	0.231* (0.0007)	--	0.201* (0.0006)	--	0.263* (0.039)
GEF	--	0.138* (0.0003)	--	0.153* (0.0008)	--	0.183* (0.033)
RQL	--	0.027** (0.0018)	--	0.021* (0.001)	--	0.030* (0.011)
HCI	--	0.662* (0.0043)	--	0.504* (0.0019)	--	0.452* (0.078)
ERI	--	0.172* (0.0013)	--	0.177* (0.0022)	--	0.127* (0.027)
GMM						
GF	0.0013 * (0.0008)	0.0031* (0.0006)	--		0.079* (0.006)	0.29* (0.0031)
EFI	--	--	0.039 * (0.0023)	0.041* (0.008)	0.139* (0.0031)	0.133* (0.002)
GF*EFI	--	--	--	--	0.131* (0.031)	0.162* (0.0061)
GDP	--	0.205* (0.015)	--	0.216* (0.0018)	--	0.287* (0.0042)
GEF	--	0.119* (0.031)	--	0.160* (0.0021)	--	0.190* (0.0042)
RQL	--	0.027** (0.017)	--	0.028* (0.002)	--	0.039* (0.002)

HCI	--	0.543* (0.027)	--	0.498* (0.0032)	--	0.51* (0.0069)
ERI	--	0.118* (0.026)	--	0.163* (0.009)	--	0.132* (0.030)
QR (0.25)						
GF	0.017* (0.0026)	0.019* (0.0044)			0.029* (0.004)	0.030* (0.0029)
EFI			0.047 * (0.0071)	0.052 * (0.0032)	0.066* (0.0049)	0.070* (0.0038)
GF*EFI					0.201* (0.0023)	0.214* (0.0031)
GDP		0.278* (0.071)		0.269* (0.0042)		0.252* (0.0031)
GEF		0.047* (0.0032)		0.032* (0.0029)		0.038* (0.0045)
RQL		0.119* (0.014)		0.0121* (0.0038)		0.012* (0.0047)
HCI		0.273* (0.0057)		0.288* (0.0047)		0.293* (0.0039)
ERI		0.039* (0.0049)		0.042* (0.004)		0.046* (0.0038)
QR (0.50)						
GF	0.021* (0.003)	0.021* (0.005)			0.032* (0.0026)	0.041 * (0.0031)
EFI			0.051 * (0.0028)	0.059 * (0.0032)	0.071* (0.006)	0.079* (0.0045)
GF*EFI					0.221* (0.0031)	0.282* (0.0052)
GDP		0.290* (0.049)		0.273* (0.039)		0.266* (0.0029)
GEF		0.057* (0.0041)		0.044* (0.0021)		0.042* (0.0033)
RQL		0.123* (0.008)		0.0133* (0.0022)		0.0143* (0.0031)
HCI		0.299* (0.0027)		0.301* (0.0031)		0.302* (0.0018)
ERI		0.059* (0.002)		0.052* (0.006)		0.054* (0.005)
QR (0.75)						
GF	0.032* (0.006)	0.043* (0.008)			0.044** (0.012)	0.056 * (0.011)
EFI			0.059 * (0.0043)	0.66 * (0.0063)	0.82* (0.014)	0.121* (0.015)
GF*EFI					0.254* (0.018)	0.299* (0.023)
GDP		0.290* (0.049)		0.293* (0.053)		0.297* (0.061)
GEF		0.057* (0.0041)		0.052* (0.0024)		0.053* (0.013)
RQL		0.176* (0.007)		0.141* (0.0019)		0.152* (0.024)
HCI		0.304* (0.0023)		0.317* (0.004)		0.356* (0.038)
ERI		0.067 (0.0028)		0.063* (0.008)		0.077* (0.019)

and EFI into our analysis. We utilized Models 5. and 6. to investigate the collective influence of GF and EFI on regulatory quality (REG). The study revealed that various control variables, including GDP, GEF, RQL, HCI, and ERI, had a positive influence on the expansion of renewable energy. Furthermore, it was observed that all of these variables contributed to the advancement of renewable energy growth across all quantiles. Based on econometric analyses, the research indicates that the growth of renewable energy is positively impacted by gross domestic product (GDP). The results obtained from the Fully Modified Ordinary Least Squares (FMOLS) and Generalized Method of Moments (GMM) approaches indicate impact coefficients of 0.263 and 0.287, respectively. Conversely, the utilization of the quantile regression (QR) methodology yields impact coefficients of 0.252, 0.266, and 0.297 for the 25th, 50th, and 75th quantiles, respectively. This research study presents an analysis of the potential influence of government effectiveness (GEF) on the outcome variable through the utilization of diverse econometric methodologies. The results suggest that the approximated effect of GEF as determined by FMOLS is 0.183, while that obtained from GMM is 0.190. Additionally, the impact of GEF from QR (25), QR (50), and QR (75) is 0.38, 0.42, and 0.053, respectively. The empirical findings obtained from the FMOLS (0.030), GMM (0.039), QR (25) (0.012), QR (50) (0.0143), and QR (75) (0.152) estimators indicate that regulatory quality (RQL) exerts a favorable influence on the REG. The impact of human capital on the expansion of renewable energy was evaluated using Fully Modified Ordinary Least Squares (FMOLS), Generalized Method of Moments (GMM), and Quantile Regression (QR) methods at different quantiles (25th, 50th, and 75th). The resulting figures were 0.452, 0.51, 0.293, 0.302, and 0.356. As per theoretical predictions, it was ascertained that each variable had a noteworthy and constructive influence. The adoption of a strategy aimed at enhancing global competitiveness through the diversification of production towards complex goods has been identified as an effective approach towards promoting renewable energy growth. Similarly, there are several additional factors that contribute to effective governance and regulatory excellence, including the competent implementation of policies and regulations at the national level, which also promote the utilization of renewable energy. The process of human resources development has been recognized as a factor that contributes to the release of greenhouse gases from energy sources, resulting in negative consequences.

Discussion

Industrial development has led to a multitude of unexpected repercussions, including the deterioration of the environment, which has had adverse effects on both human well-being and biodiversity worldwide. The aforementioned environmental issues necessitate careful deliberation to enhance comprehension of how to formulate policies pertaining to climate change. Several agreements have been made with the aim of mitigating environmental pollutants by keeping the average temperature below 2°C. Governments worldwide have increasingly focused on investing in research (R) and development (D) for RE, commonly referred to as GF, as a means of effectively mitigating greenhouse gas emissions. Presently, nations are exploring various measures to curtail carbon dioxide emissions with the aim of promoting environmental sustainability. These measures include, but are not limited to, renewable energies, eco-innovation, and carbon taxes. The United Nations has established supplementary objectives to be accomplished by 2030, which underscore the significance of accessible and uncontaminated energy (goal 7.), all-encompassing and sustainable economic expansion (goal 8.), and technological advancement (goal 9.) as mechanisms to address climate change in a pressing manner [110, 111].

The present study offers a theoretical basis for the proposition that the amalgamation of green finance and economic fitness can lead to a decline in greenhouse gas emissions and a boost in the development of RE sources within the framework of economic expansion, proficient governance and regulatory standards, advanced human capital, and economic risk. This paper examines the impact of various factors on greenhouse gas (GHG) emissions and the growth of renewable energy. These factors include sustained economic growth, changes in institutional quality such as government effectiveness and policy implementation, the development of human capital, and economic risk for clean technology innovation. The paper provides both theoretical and empirical evidence to support the promotion of industrial green upgrading and the improvement of environmental quality and consumption of renewable energy.

This is apparent from the progressively stronger coefficient of GF observed in each quantile as well as in the outcomes of FMOLS and GMM. The present findings are consistent with the results reported by Dong et al. [43] and Guo et al. [48]. Moreover, the stronger effect of GF on GHG-EN emissions was also observed by Khan et al. [112], Xian et al. [113], Yang et al. [114], and Yu et al. [115]. The underlying economic mechanism responsible for the observed correlation between GHG-En emissions and GF is that GF prioritizes investments in environmentally sustainable productions and incentivizes enterprises to develop innovative, energy-efficient innovations that are conducive to reducing carbon emissions [116]. This includes the promotion of renewable energy technological advances. In recent times, many OECD countries have implemented various environmentally sustainable financial instruments, such as green bonds, green securities, and other similar tools. These instruments have the potential to incentivize consumers as well as businesses to establish the concept of mitigating greenhouse gas (GHG) emissions by endorsing environmentally friendly initiatives in OECD countries.

Utilizing green financing to accelerate spending on projects that are environmentally friendly has been one of the most successful options in recent years. The GF mechanism is very effective in affecting and incentivizing businesses and customers toward the adoption of eco-friendly initiatives. Li et al. [117] have described that the green credit policies have remarkably reduced the energy intensity of industrial companies, with the impact of incentives on adoption being greater than the constraints. Moreover, the growing awareness of GF and sustainable competitiveness have been identified as important tools in encouraging SMEs to promote sustainable production and adopt appropriate initiatives to counter climate change [118]. Additionally, Talha [119] has described the positive impact of GF on institutions, showing that GF effectively encourages pro-environmental behavior and the development of sustainable policies. The GF reforms significantly contribute to the adoption of low-carbon energy and energy-conservative technologies [120].

The implementation of green financing mechanisms can engender confidence among individuals who invest in environmentally sustainable initiatives through the provision of bank- or government-backed guarantees. Furthermore, enhancing the profit rate on investment has the potential to render such undertakings more appealing to investors [121]. Green finance has the potential to facilitate the promotion of environmental protection initiatives in developing economies, which can result in green economic expansion and a healthy environment. Green financing instruments have emerged as a crucial consideration for investors seeking to engage in environmentally sustainable projects. These tools have the potential to mitigate the risk associated with investments by leveraging government guarantees [122]. The study's noteworthy results validate the imperative role of green regulations within green financing markets in enhancing their efficacy towards advancing the deployment of green energy [123]. Sachs et al. [124] discovered that green finance has a favorable effect on the promotion of green energy initiatives, particularly those involving small-scale energy investments. According to Zhang and Wang [125] and Polzin and Sanders [126], the implementation of green finance has the potential to facilitate the achievement of sustainable renewable energy growth in nations by drawing in private investors and fostering collaboration between the public and private sectors. According to Wang and Zhi [127], the effectiveness of green finance in promoting renewable energy growth is contingent upon the financial sector's mechanisms and government regulations that govern green finance. According to Goldstein's [128] perspective, the implementation of green economic reforms is imperative for all nations to enhance their investments in renewable energy production, thereby reducing pollution in the environment.

Various international and local organizations are advocating for the use of eco-friendly goods and services as a means of reducing the harmful impacts of industrialization. The economic prowess of a nation is indicative of its ability to tackle intricate challenges, such as global warming and environmental deterioration, which are pressing worldwide issues [129]. The Asia-Pacific Economic Cooperation (APEC), the Organization for Economic Cooperation and Development (OECD), and the World Trade Organization (WTO) have established definitions and classifications for environmental goods. As per the findings of the OECD and Eurostat, the term "environmental goods" pertains to commodities that are used for the purpose of gauging, preventing, or mitigating pollution in the environment. Therefore, the diversification of products can lead to the availability of environmentally sustainable options. Product diversification refers to the strategy of expanding the range of energy-efficient products offered by a company with the aim of mitigating environmental degradation. Within the same context, it can be argued that economic fitness represents a more comprehensive measure than product diversification, and furthermore, it is the most efficacious approach for mitigating emissions. The current outcomes are reliable with the concept of economic fitness, which has been shown to have a significant impact on mitigating environmental degradation [130]. The manufacturing of complex and diverse commodities for the worldwide market implies that trade portfolios featuring less specialized items result in greater material footprints. Meanwhile, environmentally friendly resource management is facilitated by human capital and the transition from fossil fuels to renewable energy sources [131]. The study conducted by Sharma et al. [132] investigated the relationship between diversifying exported goods and energy consumption. The authors discovered that the expansion of exports in both quantity and quality led to an increase in the demand for renewable energy, thereby promoting environmentally friendly resource management. The confluence of EFI and GF has the potential to yield a favorable impact on the expansion of renewable energy sources while simultaneously mitigating greenhouse gas emissions.

The findings indicate a positive correlation between economic growth, greenhouse gas (GHG) emissions, and renewable energy consumption, whereby an increase in economic growth is associated with a corresponding increase in GHG emissions and renewable energy consumption. Our study's findings in relation to the connection between greenhouse gas emissions and economic growth are consistent with those of Al-Mulali et al. [133], Kasman and Duman [134], and Say and Yücel [135]. Chang et al. [136] conducted a study to examine the growth in the renewable energy industry across various economic growth rates in OECD member nations. Their findings indicate that nations experiencing significant economic expansion demonstrate an ability to augment their utilization of renewable energies, whereas nations with limited economic growth exhibit a lack of capacity to enhance their adoption of renewable energies. The relationship between economic growth and RE consumption varies between developed and developing nations. The developed nations experience a noticeable and positive impact on their economic growth due to their increased usage of RE [137]. Moreover, there exists a protective effect in developed nations, whereby an increase in self-sustainable growth can positively affect their economic growth [138]. Conversely, in developing nations, decreased energy consumption could hinder their economic growth [139]. In the case of developed nations, the implementation of their effective policies regarding the promotion of the adoption of renewable energy sources can substantially contribute to their economic growth. However, in the case of developing countries, it is very important to maintain the balance between energy storage policies and their economic growth [140]. In their study, Apergis and Payne [141] employed panel cointegration and an error correction model to examine the causal nexus between renewable energy and economic growth across twenty OECD nations. The research reveals that a sustainable association exists in the long term between the consumption of renewable energy and real GDP. Similarly, Lin and Moubarak [142] also described similar results regarding the relationship between economic growth and the growth of renewable energy.

The provision of a conducive business environment to local enterprises and investors can facilitate the achievement of sustainable environments and the adoption of renewable energy sources. Therefore, it is recommended that domestic enterprises embrace eco-friendly energy technologies, such as renewable energy. The conduct exhibited by companies within the nation is contingent upon the presence of favorable institutional circumstances. The institutional circumstances that favor prosperity and progress play an important role in developing positive company conduct. A well-defined regulatory framework, supportive policies, and robust governance structure provide a solid decision-making framework for the companies. This results in fostering trust among investors, which boosts corporate responsibility and leads toward the adoption of eco-friendly and sustainable business practices. Thus, the companies become more likely to innovate and make substantial contributions to both economic and environmental goals. The assurance of an economic actor is positively impacted by the establishment of secure property rights, universal adherence to regulations, and the successful implementation of efficacious policies. Thus, it is imperative to ensure the efficacy of governmental operations and the quality of regulations in order to enhance the sustainable integration of energy technologies and mitigate greenhouse gas emissions. Effective government operations streamline approval procedures and develop an environment that encourages innovation. Similarly, high-quality regulations offer clear guidelines, establish the framework for responsible industry practices, and incite the adoption of RE technologies. Ultimately, these elements, like GEF and REG, work together to create a resilient and eco-friendly energy landscape that promotes the seamless integration of modern technologies. The attainment of sustainable, environmentally friendly goals is heavily influenced by effective regulations and high-quality governance [143]. The study conducted by Samimi et al. [144] investigated the quality of regulation and environmental deterioration in the MENA region using a CO2 emission proxy. The authors noted that developing countries require solid and assertive policies to address climate anomalies and foster ecological sustainability. Stef and Jabeur [145] reported that regulation has a noteworthy positive effect. According to Peimani's [146], there exists a negative correlation between income level and regulatory quality with regards to GHG emissions in developed nations. This finding also highlights the effectiveness of policy measures aimed at promoting direct investment from the private sector in renewable energy projects.

The development of human capital is a crucial factor in reducing greenhouse gas emissions, as it involves the acquisition and application of specialized knowledge. Research has demonstrated that the application of knowledge, which is dependent on proficient human capital, has the potential to decrease the utilization of non-renewable energy sources [147]. Furthermore, enhancements in human capital would result in an improved comprehension of the significance of both ecological and energy sustainability [148, 149]. The significance of human capital and renewable energy in mitigating polluting petrol emissions has been extensively documented in academic literature [150-153]. According to Alvarado et al. [154], the presence of human capital plays a crucial role in enabling the development and establishment of environmentally friendly renewable energy sources that are economically feasible for the general public. Human capital has a crucial role in reducing GHG emissions. Investment in education and promoting knowledge sharing can significantly contribute to environmental sustainability and address the challenges of climate change. Similarly, the development of human capital also serves as a powerful tool in lowering the detrimental impact of non-RE use on environmental quality. Therefore, various studies have described the inverse relationship between human capital and carbon dioxide emissions [155-158].

This is apparent from the escalating magnitude of the ERI coefficient across consecutive quantiles. Insufficient stability in economic policy may lead to reduced economic activity and subsequently a decrease in energy demand. Economic risk often reduces economic activities, which in turn causes a decline in energy demand as industries reduce their production levels and consumers limit their expenditures. Although this downturn in economic activities temporarily decreases GHG emissions, decoupling economic growth from carbon-intensive practices is necessary for long-term sustainability. The findings of our study provide corroboration for the argument posited by Adedoyin and Zakari [53] that economic risk serves to mitigate greenhouse gas (GHG) emissions. According to Wang et al. [42], the positive effect of ERI on GHG emissions can be attributed to the economic institution wherein ERI diminishes the expansion of output, ultimately resulting in the reduction of GHG emissions.

Conclusions

Rising temperatures, a changing climate, and increasing GHG emissions exert pressure on economies to adopt different sustainable policies and practices at the micro and macro levels. All economic activities are impossible without the consumption of energy, and non-renewable energy sources are the majority consumed around the world. The contribution of non-renewable energy to greenhouse gas emissions is highly undesirable, and economies have turned towards the promotion of renewable energy use. In this context, economies around the world have started to adopt effective policies to reduce GHG emissions and adopt green energy sources. Green financing and economic fitness are the strategies that were expected to reduce GHG emissions and enhance renewable energy growth.

The study investigates the correlation between green financing (GF) and economic fitness (EFI) in relation to the expansion of renewable energy and the reduction of greenhouse gas emissions in OECD economies. The escalation of energy needs and industrial development in these countries has significantly amplified energy consumption, leading to worldwide human affliction and a decline in biodiversity. Contemporary scholars are currently investigating strategies to mitigate carbon dioxide emissions with the aim of enhancing the ecological sustainability of our planet. This is being accomplished through the exploration of topics such as renewable energy sources. The study of reducing the environmental effects of energy use can provide a foundation for the development of policies related to energy and the environment. This study posits that the proliferation of green financing and its positive impact on economic viability could potentially mitigate challenges associated with the shift towards sustainable green energy sources. The present research assesses the association between green financing and economic fitness, greenhouse gas (GHG) emissions, and the expansion of renewable energy in OECD nations, employing the methods of Quantile Regression (QR), Generalized Method of Moments (GMM), and Fully Modified Ordinary Least Squares (FMOLS). Furthermore, our study has examined the separate and joint impacts of green finance and economic fitness on greenhouse gas emissions and the expansion of renewable energy. Furthermore, we examine the impact of Gross Domestic Product (GDP), economic risk, effectiveness of government, quality of regulations, and human capital on greenhouse gas emissions and the expansion of renewable energy sources. The results depict that both the GF and EFI have the capacity to mitigate greenhouse gas emissions and enhance the utilization of renewable energy sources. The synergistic impact of the integration of green finance (GF) and EFI suggests that nations have the potential to substantially mitigate greenhouse gas (GHG) emissions and increase the adoption of renewable energy sources. Furthermore, the empirical evidence suggests that economies with high carbon emissions exhibit a more favorable response to green financing and EFI compared to low carbon-emitting economies. The influence of GF on greenhouse gas emissions exhibits a more pronounced effect in countries with comparably higher emissions, while its effect is comparatively less significant in countries with lower emissions. Furthermore, it has been observed that proficient governance, superior regulatory frameworks, economic stability, and skilled human resources play a crucial role in mitigating the escalation of greenhouse gas emissions in nations with both high and low emission levels. On the contrary, it can be observed that Gross Domestic Product (GDP) has a significant impact on the emission of greenhouse gases (GHG) across all Organization for Economic Cooperation and Development (OECD) member countries. The utilization of renewable energy in economies can be improved through the incorporation of crucial factors such as GDP, effective government, quality regulations, economic risk, and human capital.

It is suggested that governmental assistance and dedication hold significant pertinence in endeavors pertaining to the development of sustainable energy technologies. Offering financial incentives is imperative in promoting the fast adoption of RE technology among self-contained enterprises and households. The implementation of tax holidays as rewards for societies interested in installing clean energy producing appliances can facilitate the achievement of this objective.

It is imperative to enhance private investment as there exists a likelihood that environmental endeavors lacking sufficient government support may receive monetary aid from the business community.

Apart from governmental regulation and guidance, it is imperative for the pertinent ministries to improve green bond monitoring and green finance companies' corporate social responsibility.

It is recommended that economies facilitate firms in the adoption of renewable energy sources and the reduction of greenhouse gas emissions in order to enhance economic resilience, particularly for firms and industries that manufacture complex and diverse products.

It is important to notice some limitations of the current study. For example, the current study solely focused on the OECD countries, which limited the general applicability of the findings on a global scale. Therefore, for reliable understanding and more universal applicability of the relationship between GF and EFI and sustainable energy outcomes, future research should extend its scope to include non-OECD countries.

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Data Availability Statement

The data can be obtained from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare no conflict of interest.

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