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Green Investment as a Buffer: Analyzing the Economic and Environmental Impacts of Non-Renewable Energy Consumption in G20 Countries

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Abstract: The G20 countries are among the world's fastest-growing economies. However, they are also major contributors to environmental degradation, as most of them rely heavily on non-renewable energy sources to support economic growth. This study investigates the moderating role of green investment in the relationships between non-renewable energy consumption, economic growth and environmental degradation in G20 countries. A panel data approach was used to analyze data from G20 countries for the period 2010 to 2023. The study employed the panel-corrected standard error (PCSE) method as the main estimator, supplemented by a feasible generalized least squares (FGLS) model for robustness checks. Additionally, to address endogeneity in panel data, a one-step system generalized method of moments (GMM) regression was used, which provides consistent estimates in dynamic panels. The findings indicate that non-renewable energy consumption has a significant positive effect on economic growth but also significantly increases environmental degradation. Furthermore, the moderation results show that green investment strengthens the positive effect of non-renewable energy consumption on economic growth and reduces its negative environmental effects. Hence, policymakers in G20 countries should promote green investment initiatives to mitigate the environmental challenges associated with the consumption of non-renewable energy resources.

Keywords: environmental degradation; economic growth; non-renewable energy consumption; green investment.

JEL classification: C10; C50; Q56.

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1. INTRODUCTION

Consumption of non-renewable energy has long been linked to the pursuit of economic growth. In the context of national development strategies, economic development is the primary goal of every country (Adanma and Ogunbiyi, 2024). Due to the rising need for energy, researchers in energy economics have extensively examined the link between energy consumption and economic growth (Pegkas, 2020; Asiedu *et al.*, 2021; Cevik *et al.*, 2021; Ivanovski *et al.*, 2021). Yet research outcomes on both variables have generally been ambiguous, suggesting a lack of consensus among scholars. The primary factors contributing to this uncertainty are geographical differences, econometric methods, and the diverse characteristics of different countries. Besides being effective catalysts for economic growth, non-renewable energy sources also contribute to ecological deterioration (Amin *et al.*, 2022). Economic growth is linked to energy consumption, and energy usage contributes to environmental degradation (Wen *et al.*, 2021; Usman *et al.*, 2023). Currently, almost every country meets the bulk of its energy requirements through non-renewable energy resources. Therefore, as countries' energy consumption increases, environmental degradation also grows (Islami *et al.*, 2022). The main challenge today is to maintain equilibrium between sustainable economic expansion and environmental concerns.

The world is currently confronted with escalating environmental degradation, which is destructive to human life (Shivanna, 2022). Several countries have failed to implement energy-efficient technologies in manufacturing processes. That is why their economic activities continue to rely on energy-inefficient methods, contributing to global environmental degradation (Yang *et al.*, 2021; Chin *et al.*, 2022). Growing consumption of non-renewable energy is accelerating environmental degradation, leading to significant CO_2 emissions worldwide (Asif *et al.*, 2021). Energy-related CO_2 emissions worldwide rose by 1.1% in 2023, climbing 410 million tonnes to achieve an unprecedented total of 37.4 billion tonnes (IEA, 2024). This statistic highlights the ongoing degradation of the environment and underscores the urgent need for more sustainable economic development. Indeed, the world is experiencing a significant degradation of environmental conditions. This environmental degradation is primarily driven by the extensive consumption of non-renewable resources in the pursuit of economic development (Pegkas, 2020; Cevik *et al.*, 2021). Consequently, green investment has become imperative, particularly for countries that remain heavily dependent on non-renewable energy sources (Güney, 2019). Such environmentally sustainable investments not only support economic growth but also contribute to environmental preservation. Against this backdrop, the present study seeks to examine whether green investment can mitigate the environmental and economic consequences of non-renewable energy consumption.

The G20 countries have considerable influence on global economic, environmental and energy dynamics. The G20 nations collectively account for about 85% of global GDP, 75% of international trade and two-thirds of the world's population (Munyati, 2023). Consequently, their energy and environmental policies exert a significant influence on the global environment. Notably, like many other countries around the world, G20 nations continue to meet the majority of their energy demands through non-renewable energy sources (Ajide and Mesagan, 2022; Shah *et al.*, 2024). Fossil fuel consumption of most G20 countries has been rising. The overall consumption of fossil fuels by G20 countries was 92,804 TWh in 2010, and this increased to 107,585 TWh by 2023, representing an increase of approximately 15.93% (Our World in Data, 2025). Figure no. 1 presents the fossil fuel

consumption tendencies in G20 countries, with India having the highest growth in consumption (+67%) and the United Kingdom having the lowest (-36%).

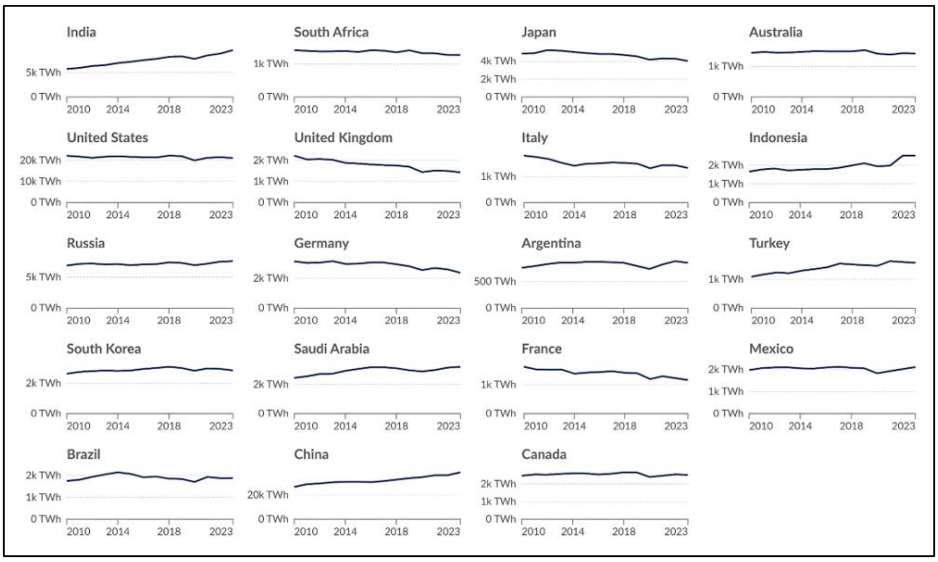

Figure no. 1 – Trends in fossil fuel consumption across G20 countries, 2010 to 2023

This 15.93% increase in fossil fuel consumption is one reason behind the upsurge in CO_2 emissions to the environment worldwide. The CO_2 emanating from non-renewable sources is giving rise to various environmental consequences. These outcomes include global warming, an increase in sea levels, and threats to ecosystem balance. The total CO_2 emissions by G20 countries increased by 15% from 2010 to 2023 (Ritchie *et al.*, 2023). Figure no. 2 shows the trend of CO_2 emissions by G20 countries from 2010 to 2023. India had the highest increase in emissions, at +83%, and the United Kingdom had the lowest, at -40%.

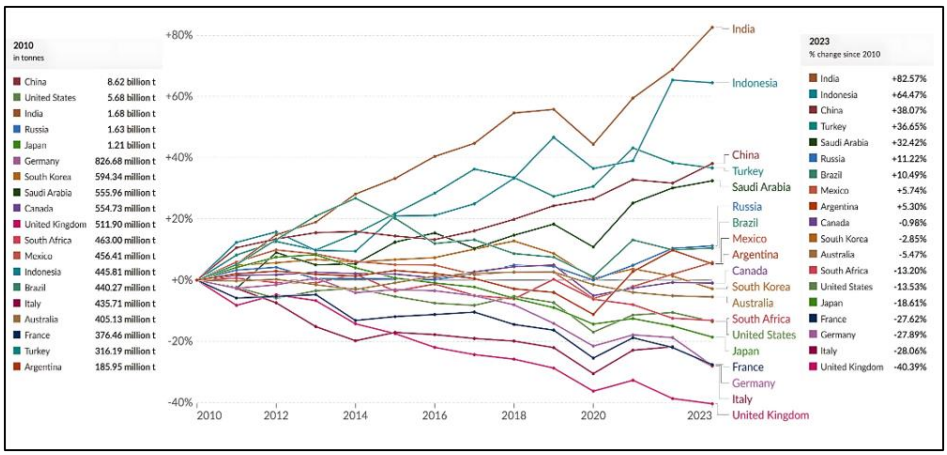

Figure no. 2 – The trend of relative changes in CO_2 emission among G20 members from 2010 to 2023

Statistics show that G20 countries with high consumption of non-renewable resources also contribute extensively to the degradation of the world environment. Their heavy dependence on non-renewable energy resources significantly contributes to the worsening of global environmental challenges. Fossil fuel dependence and carbon emissions remain substantial across the G20, though patterns differ among individual economies. G20 members at the 2023 summit emphasized the need to expand green finance to address environmental degradation concerns. The G20 leaders further emphasized their conviction that financial flows should be aligned with the climate goals established under the Paris Agreement (Citil, 2024). The emphasis on green investment is increasing worldwide due to the growing concerns about environmental degradation. These commitments raise an important empirical question: does greater green investment weaken the environmental cost of non-renewable energy while improving its contribution to economic growth?

Recent research has broadened the literature regarding the association among energy use, environmental policies, and economic results. Ozcan *et al.* (2020) analyze the 35 OECD member countries and conclude that higher levels of economic development, combined with improved energy efficiency, lead to better environmental outcomes. Likewise, Chien (2022) indicates that excessive consumption of fossil energy fuels economic growth of the N-11 economies but also exacerbates the environmental situation. Wang *et al.* (2023) further show that non-renewable energy promotes long-run economic growth in selected Northeast Asian nations. However, it also intensifies long-run CO_2 emissions. The results indicate that non-renewable energy provides economic benefits; however, it is also a significant factor in environmental problems. These studies provide important evidence regarding the associations among non-renewable energy consumption, environmental degradation and economic growth, but they primarily focus on direct associations, individual environmental outcomes, and countries with different characteristics. However, there are several gaps in the literature related to these relationships. Firstly, previous studies focus on either environmental or economic impacts of non-renewable energy consumption. This represents an incomplete measure of the benefits and costs of fossil fuel dependence. Second, these studies considered green investment as only a direct determinant of growth and environmental quality. These studies do not fully establish whether green investment changes both the economic and environmental effects of non-renewable energy consumption in G20 economies. There is limited evidence on whether green investment moderates the relationship between non-renewable energy consumption and the study outcomes. Third, the net impacts of different levels of green investment on the G20 economies when using non-renewable energy have not been studied. The novelty of the present study lies not in re-examining the direct relationship among energy consumption, economic growth, and environmental quality. Rather, it investigates the conditional role of green investment within an integrated economy-environment framework. Further, it analyzes the net effects of non-renewable energy consumption at different levels of green investment. This study seeks to fill the research gap by examining the extent to which green investment can mitigate the environmental consequences of non-renewable energy consumption while sustaining economic progress.

Green investment can alter these relationships through several channels. It may weaken environmental damage by supporting energy efficiency, cleaner production, and low-carbon technologies (Umar and Safi, 2023; Cheng and Zhu, 2024). It may also influence the growth effect of non-renewable energy by improving resource efficiency and technological

productivity (Hussain *et al.*, 2025; Adil *et al.*, 2026). However, its moderating effect on economic growth is not automatically positive. Green investment may complement conventional energy during the transition toward cleaner production. Furthermore, it may encourage substitution away from fossil fuel-based activities (Doğan *et al.*, 2026). The direction and magnitude of this moderating effect therefore require empirical examination. Accordingly, this study pursues three main objectives. First, it analyzes the impact of non-renewable energy consumption on economic growth in G20 economies. Secondly, it examines the impact of non-renewable energy consumption on environmental degradation. Third, it investigates how green investments influence the relationship between non-renewable energy consumption, economic growth, and environmental degradation. Along with estimating the interaction coefficients, the study computes the corresponding net effects to explain the moderating relationships in an economically meaningful way.

This study makes four contributions to the existing literature. First, it explores the economic and environmental implications of non-renewable consumption within a single empirical framework. Second, in addition to examining the direct impact, it extends the literature on environment-focused investments by analyzing green investment as a moderating mechanism. Third, it estimates and interprets the net consequences of non-renewable energy consumption at varying levels of green investment, providing greater clarity regarding the practical implications of the interaction terms. Fourth, it presents evidence from the G20 economies, which are globally significant yet economically and institutionally diverse. Moreover, it examines the robustness of the findings using multiple panel estimation methods. The study comprehensively investigates these relationships using data from G20 countries, which account for a substantial share of global economic activity, energy consumption, and carbon emissions. Hence, to achieve the objectives, the study estimates the relationships through two econometric approaches, panel-corrected standard errors (PCSE) and feasible generalized least squares (FGLS). Both approaches yield reliable estimates in the presence of cross-sectional dependence, serial correlation, and heteroskedasticity. In addition, the one-step system generalized method of moments (GMM) estimator is employed to address potential endogeneity concerns associated with the main findings. The interaction terms are interpreted through net effect calculations and marginal effect plots. The remainder of the paper reviews the relevant literature, explains the research methodology, and presents the main and robustness results. Consequently, the policy recommendations derived from the study's primary findings will help promote sustainable economic development in these countries and enhance the quality of the global ecosystem.

2. LITERATURE REVIEW

2.1. Non-Renewable Energy Consumption and Economic Growth

Ivanovski *et al.* (2021) examined how the effects of non-renewable energy consumption on economic growth change over time in both OECD and non-OECD nations from 1990 until 2015. The study applied a local linear dummy variable estimation technique, and it argued that this approach does not require any assumptions about functional form and is more effective in capturing non-linear relations. Hence, their analysis suggested that non-renewable energy consumption significantly influences economic growth in both OECD and non-OECD countries. Furthermore, Asif *et al.* (2021) reported that the

use of non-renewable energy resources significantly promotes economic growth. Their study examined panel data from 99 countries spanning the period 1995 to 2017, employing dynamic OLS (DOLS), fully modified OLS (FMOLS), and fixed-effects estimation techniques. Moreover, Pegkas (2020) found that the use of non-renewable energy fostered long-run economic growth in Greece. However, Cevik *et al.* (2021) found a bidirectional link between energy usage and economic development in the USA. They identified that the use of non-renewable energy is crucial for the USA's economic progress. Rahman and Velayutham (2020) analyzed the data from five South Asian nations using panel FMOLS and DOLS assessment approaches. Their study found that non-renewable energy consumption contributes to a 0.10% increase in economic growth. Moreover, Mohammadi *et al.* (2023) analyzed the selected advanced and underdeveloped countries from 1993 to 2019 through an OLS approach. Their study results highlighted the constructive role of non-renewable energy consumption on the economic progress of both categories of countries. Consequently, by considering the discussion outlined above, we propose that:

H1*: Non-renewable energy consumption significantly positively influences economic growth.*

2.2. Non-Renewable Energy Consumption and Environmental Degradation

Chien (2022) analyzed panel data from the N-11 economies covering the period 1990-2020 using the MMQR approach to examine the relationship between non-renewable energy consumption and environmental degradation. The study's findings demonstrated that using non-renewable resources positively impacts ecological settings; however, this impact is only at minor quantiles (0.10–0.40). Moreover, in response to Australia's growing environmental challenges in recent years, Rahman and Alam (2022) investigated the roles of several environment-related factors. Employing the ARDL model and Granger causality tests, their study found that non-renewable energy consumption exerts a positive effect on environmental degradation. Furthermore, Randhawa *et al.* (2026) found that technological innovation plays an important role in shaping environmental stress in Pakistan. Their study further supports the need to consider complementary factors beyond energy consumption when examining environmental outcomes. Moreover, Adekoya *et al.* (2024) examined the relationship between energy consumption and ecological degradation by distinguishing between oil-importing and oil-exporting countries. Using the AMG regression technique, their study found that the use of non-renewable resources in both groups of countries plays a substantial role in environmental deterioration. However, their study further revealed that this effect is more pronounced in oil-exporting countries. This is because of their substantial reliance on crude oil and energy inefficiencies. In addition, combating climate change has become a central objective of policy initiatives across Sub-Saharan African countries in recent years. Therefore, Ahmad Khan *et al.* (2024)investigated Sub-Saharan African nations because of their strong commitment to achieving sustainable targets. According to their two-step system GMM regression findings, the use of non-renewable energy positively impacts the environment. Additionally, Zhang *et al.* (2024) analyzed Chinese data from 1991 to 2020 to examine the impact of non-renewable energy consumption on CO_2 emissions. Using the QARDL approach, the study revealed that the consumption of non-renewable energy is positively associated with CO_2 emissions. Thus, by considering the discussion outlined above, we hypothesize that:

H2*: Non-renewable energy consumption contributes to environmental degradation.*

2.3. Moderating Role of Green Investment

Dong *et al.* (2024) found that carbon emissions are greatly curtailed in an economy that values green investment. Beşer *et al.* (2025) examined the annual data of 20 African nations from 2000 to 2019 by employing the GMM estimator and found that green investments can positively tackle the environmental degradation issues. More recently, Solangi and Magazzino (2025) examined the relationship between natural resource management and green energy investment in Gulf Cooperation Council countries. Their study suggests that investment in cleaner energy sources can play an important role in improving environmental outcomes. Similarly, Solangi *et al.* (2025) investigated the role of green finance in sustainable development across 16 emerging market economies during 2014 to 2022. Their findings showed that green finance has a positive effect on sustainable development. Their study highlighted the importance of increasing green investment to tackle the environmental challenges. In contrast, Onifade *et al.* (2025) argued that green investments promote sustainable economic development rather than hinder it. Wan and Sheng (2022) analyzed panel data from 30 Chinese provinces and cities covering the period from 2003 to 2017. Their findings confirmed the significant positive contribution of green investment to economic development. Furthermore, the study suggested that green investment is an effective means of stimulating economic growth. In light of the debate above, we hypothesize that:

H3a: *Green investment significantly moderates the association between non-renewable energy consumption and economic growth.*

H3b: *Green investment significantly moderates the association between non-renewable energy consumption and environmental degradation.*

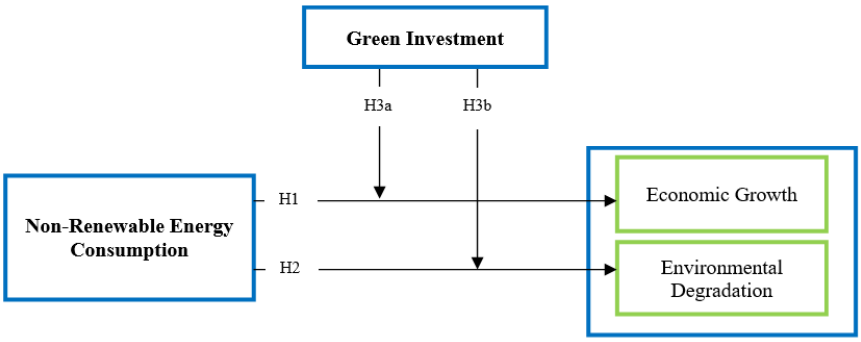

Figure no. 3 – Conceptual framework of the current study

3. DATA AND METHODOLOGY

3.1. Database and Variables

We have chosen a panel dataset of G20 countries covering the years 2010 to 2023. The sample includes 19 countries, each with 14 years of data. Consequently, our dataset has a

large number of cross-sections *(N)* as compared to time periods *(T)*. Our independent variable is non-renewable energy consumption *(lnNREC)*, measured as per capita fossil fuel consumption in kWh. Furthermore, we have employed two dependent variables, namely economic growth *(lnEG)* and environmental degradation *(lnED)*. We gauged economic growth by the annual percent change in real GDP. Environmental degradation is assessed by CO_2 emissions from fossil fuels and industry in billion tonnes. Moreover, we incorporated green investment *(lnGI)* as a moderator variable, measured by government funds allocated for environmental protection as a percentage of GDP. We also included trade openness *(lnTO)*, foreign direct investment *(lnFDI)* and COVID19 as control variables.

The measurements of all variables were in different units. Therefore, we transformed them into logarithmic form following Appiah-Otoo *et al.* (2023) and Sun *et al.* (2022) to obtain more accurate estimates. The data for non-renewable energy consumption and environmental degradation were obtained from the Our World in Data database. Furthermore, the statistics regarding economic growth and green investment were gathered from the International Monetary Fund. We fetched the data on trade openness and foreign direct investment from the World Development Indicators database. Thus, we created a sample panel dataset that integrates both cross-sectional and time-series data characteristics. Also, it provides better information, greater efficiency, lower collinearity, and higher degrees of freedom (Baltagi, 2008; Hsiao, 2022). Table no. 1 provides a separate description of each variable along with the source.

Table no. 1 – Description of Variables

Variable	Acronym	Description	Source
Non-Renewable Energy Consumption	lnNREC	Fossil fuels per capita (kWh)	Our World in Data
Economic Growth	lnEG	Real GDP growth (annual percent change)	IMF
Environmental Degradation	lnED	CO_2 emissions from fossil fuels and industries, measured in billion tonnes	Our World in Data
Green Investment	lnGI	Funds allocated by the government for environmental protection as a percentage of GDP	IMF
Trade Openness	lnTO	Trade (% of GDP)	WDI
Foreign Direct Investment	lnFDI	The net value of foreign direct investment (FDI) equity flows into a country, quantified in terms of current U.S. dollars	WDI
COVID19 Pandemic	COVID19	It indicates the presence (1) or absence (0) of COVID-19 epidemic influence	Binary Variable

Note: authors' compilation

3.2. Model Specification and Methodology

The empirical models are developed to examine both the direct effects of lnNREC and the moderating role of lnGI. The underlying intuition is that lnNREC can support economic activity by providing the energy required for production, transportation and other economic activities. However, greater dependence on non-renewable energy can also increase lnED through higher carbon emissions. Therefore, the effect of lnNREC cannot be evaluated only from an economic perspective (Tiba and Omri, 2017; Vincent and Ezaal, 2022).

lnGI is introduced as a moderating variable because it may change the effects of lnNREC. Khan *et al.* (2023) argued that higher lnGI can reduce the environmental damage associated with lnNREC by supporting energy efficiency and environmentally friendly production processes. Similarly, Kwilinski *et al.* (2023) suggested that lnGI can influence the economic effects associated with lnNREC by improving resource efficiency and supporting the transition toward cleaner production. Therefore, the interaction between lnNREC and lnGI is included in the empirical models to determine whether the level of lnGI changes the proposed relationships. Figure no. 3 presents the conceptual model of the current study.

Accordingly, the interaction term between lnNREC and lnGI captures the conditional effects of lnNREC. A statistically significant interaction coefficient indicates that the effect of lnNREC depends on the level of lnGI. The corresponding net effects are also calculated at different levels of lnGI to provide a clearer interpretation of the interaction effects. To examine the effect of lnNREC on lnEG and lnED, the following baseline regression models are estimated.

$$lnEG_{i,t} = \propto + \beta_1(lnNREC_{i,t}) + \beta_2(lnGI_{i,t}) + \left(\sum \beta_k\, Controls_{i,t}\right) + \varepsilon_{i,t} \quad (1)$$

$$lnEG_{i,t} = \propto + \beta_1(lnNREC_{i,t}) + \beta_2(lnNREC \times lnGI_{i,t}) + \beta_3(lnGI_{i,t}) + \left(\sum \beta_k\, Controls_{i,t}\right) + \varepsilon_{i,t} \quad (2)$$

$$lnED_{i,t} = \propto + \beta_1(lnNREC_{i,t}) + \beta_2(lnGI_{i,t}) + \left(\sum \beta_k\, Controls_{i,t}\right) + \varepsilon_{i,t} \quad (3)$$

$$lnED_{i,t} = \propto + \beta_1(lnNREC_{i,t}) + \beta_2(lnNREC \times lnGI_{i,t}) + \left(\sum \beta_k\, Controls_{i,t}\right) + \varepsilon_{i,t} \quad (4)$$

Table no. 2 – Model parameters and notation

Symbol	Definition
α	Constant term
β_1	Coefficient of lnNREC
β_2	Coefficient of lnGI
β_3	Coefficient of lnNREC × lnGI
β_k	Coefficients of control variables
i	Country
t	Year
N	Number of countries
T	Number of years
ε_{it}	Error term
lnNREC	Non renewable energy consumption
lnEG	Economic growth
lnED	Environmental degradation
lnGI	Green investment
lnNREC × lnGI	Interaction term

In Equations (1) to (4), α represents the constant term, while β_1, β_2, β_3 and β_k represent the coefficients of the explanatory, moderating, interaction and control variables, respectively. The subscripts i and t denote country and year, respectively, while N and T represent the number of countries and years. The term ε_{it} represents the error term for

country *i* in year *t*. The *lnNREC* denotes non-renewable energy consumption, *lnEG* denotes economic growth, *lnED* denotes environmental degradation and *lnGI* denotes green investment. Further, the interaction term *lnNREC* × *lnGI* is included to examine the moderating role of green investment. The notation and parameters used in the model specifications are summarized in Table no. 2.

In empirical models, we adopted environmental degradation *(carbon dioxide emissions in billion tonnes)* and economic growth *(annual percent change in real GDP)* as dependent variables, following Gür (2022) and Landefeld *et al.* (2008). The basic research framework of this study examines the direct impact of non-renewable energy consumption on economic growth and environmental deterioration, while also addressing the moderating role of green investment. The models include an interaction term between lnNREC and lnGI. Therefore, the coefficients cannot be interpreted separately. Therefore, we calculated the conditional effects of the variables included in the interaction terms by following Ullah *et al.* (2025). The conditional effect of lnNREC is calculated as:

$$\frac{\partial Y_{it}}{\partial \ln NREC_{it}} = \beta_1 + \beta_3 \ln GI_{it} \tag{5}$$

Here, Y_{it} represents either lnEG or lnED. The coefficient $\beta_1$represents the effect of lnNREC when lnGI equals zero. The coefficient β_3 shows how the effect of lnNREC changes with the level of lnGI. The conditional effects of lnNREC were calculated at low, mean, and high levels of lnGI. The low level was defined as one standard deviation below the mean. The high level was defined as one standard deviation above the mean. Further, we also constructed the interaction plots. These plots illustrate the predicted values of lnEG and lnED at low and high levels of lnNREC across low and high levels of lnGI. This procedure was conducted separately for each dependent variable model.

We used panel data in which N > T. As a result, the dataset exhibits both cross-sectional and time-series characteristics. During panel data analysis, issues such as heteroskedasticity, cross-sectional dependence, and autocorrelation may arise and must be addressed to ensure reliable estimation results. Therefore, this study employs the Feasible Generalized Least Squares (FGLS) and Panel-Corrected Standard Errors (PCSE) estimation techniques instead of panel OLS. The rationale is that the PCSE and FGLS regression methods are effective estimation techniques when the data exhibit heteroscedasticity, serial correlation, and cross-sectional dependence (Parks, 1967). First, we conducted heteroskedasticity, autocorrelation, and cross-sectional dependence analyses, and their outcomes provided the grounds in favor of the PCSE and FGLS estimators. We implemented the PCSE statistical technique as our primary regression due to its practicality for cross-section-dependent data. Beck and Katz (1995) highlighted that the FGLS statistical technique causes underestimated standard errors in the analysis that the PCSE estimator can correct. Nevertheless, Reed and Webb (2010) disagreed with these assertions and advocated for the advantages of the FGLS estimator. In line with this, we included the FGLS estimator in our investigation to increase the reliability of our findings.

4. EMPIRICAL RESULTS AND DISCUSSION

Empirical analysis involves the application of various statistical techniques to obtain a thorough understanding of the characteristics of the data. Selecting appropriate regression methods without a comprehensive analysis of the data is largely speculative, as the key regression estimates must align with the identified characteristics of the dataset. Therefore, this section employs several statistical tests to characterize the data, and the main empirical findings are presented to draw statistical conclusions regarding the proposed relationships. Table no. 3 presents the descriptive statistics of the study variables. The dataset consists of 266 observations for each variable, forming a balanced panel of data from 19 countries. The mean value of lnEG is 1.002, with values ranging from -1.600 to 2.434. The mean value of lnED is 20.325, while lnNREC has an average value of 7.979. The relatively wide ranges of lnED and lnNREC show substantial variation in environmental degradation and non-renewable energy consumption across the G20 economies. The mean value of lnGI is 0.5895 with a standard deviation of 0.2972. This variation supports the moderating role of green investment.

Table no. 3 – Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnEG	266	1.002	0.803	-1.609	2.434
lnED	266	20.325	1.114	17.886	23.2
lnNREC	266	7.979	0.94	6.603	10.563
lnGI	266	0.5895	0.2972	0.0357	1.2616
lnFDI	266	22.829	5.668	-1.273	26.96
lnTO	266	3.919	0.36	3.113	4.659
COVID19	266	0.286	0.453	0	1

Note: Calculated by authors. Descriptive statistics are based on the original variables before logarithmic transformation. The logarithmically transformed variables are used in the subsequent empirical estimations.

Figure no. 4 shows the findings of the pairwise correlation analysis along with the variance inflation factor (VIF). The degree and direction of the linear association among the study variables are evaluated through pairwise correlation analysis for all possible combinations of variables. High correlation coefficients among variables may indicate multicollinearity (Mansfield and Helms, 1982). Variables that introduce multicollinearity into the econometric model should be carefully examined because strong correlations among explanatory variables can distort regression estimates and compromise the reliability of the results. In our situation, the correlation values are well within acceptable limits. It indicates a low probability of significant multicollinearity among the variables.

In addition to pairwise correlation analysis, we have also employed the VIF test to allay apprehensions about multicollinearity. Studenmund (2000) noted that a VIF exceeding 10 may indicate multicollinearity. The results of the VIF test are encouraging, as the calculated VIF values for all variables are close to 1, suggesting the absence of multicollinearity in the model. Furthermore, Table no. 4 reports the results of the panel unit root tests. Significant Levin-Lin-Chu and Harris-Tzavalis test statistics lead to the rejection of the null hypothesis that all panels contain a unit root, thereby supporting the alternative hypothesis that all panel series are stationary. In contrast, significant Hadri LM test statistics lead to the rejection of the null hypothesis of stationarity, thereby supporting the alternative

hypothesis that at least some panel series contain a unit root. The results show that some variables are stationary at level, while others become stationary after first differencing. Consequently, these tests confirm the stationarity properties of the variables under study.

Table no. 5 reports the results of the cross-sectional dependence tests. We examined cross-sectional dependence using the Pesaran CD and Breusch-Pagan LM tests. Testing for cross-sectional dependence is essential in panel data analysis, as ignoring it may lead to unreliable results in panel estimation. In our analysis, the p-values for all models (Models 1-4) in both tests are below the 1% significance level, indicating cross-sectional dependence in the data. Therefore, we reject the null hypothesis of cross-sectional independence.

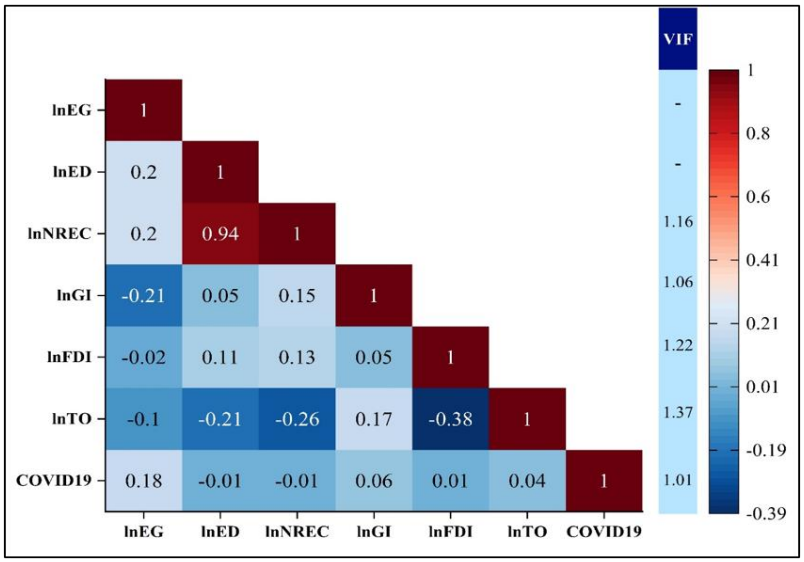

Figure no. 4 – Pairwise correlations and variance inflation factor (VIF) results for the study variables

Table no. 4 – Results of Panel Unit Root Tests

Variable	Levin–Lin–Chu		Harris-Tzavalis		Hadri LM	
	Level	First Difference	Level	First Difference	Level	First Difference
lnEG	-8.2802***	-12.1334***	-0.0775***	-0.5031***	0.2275	-3.5782
lnED	0.9823	-9.7932***	0.8669	-0.1966***	27.1350***	-1.5992
lnNREC	0.4294	-9.3889***	0.8472	-0.1277***	25.0253***	-1.5682
lnGI	-27.5156***	-25.5375***	0.6499***	-0.0648***	15.3404***	-2.0634
lnFDI	-4.6470***	-9.7897***	0.1469***	-0.3600***	0.7780	-2.8971
lnTO	-4.3380***	-13.3797***	0.6847***	-0.0759***	18.1759***	-2.1179
COVID19	2.1227	-6.5207***	0.9000	-0.0909***	21.3087***	-0.8939

Note: The asterisk symbols (*, **, and ***) denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table no. 5 – Results of Cross-Sectional Dependence Tests

	Model 1	Model 2	Model 3	Model 4
Pesaran CD test	8.469***	8.721***	8.837***	7.962***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Breusch-Pagan LM test	565.386***	574.441***	533.367***	528.164***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Note: The figures in the parentheses are p-values. The asterisk symbols (*, **, and ***) denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table no. 6 presents the results of the Modified Wald and Wooldridge tests. The test statistics from the Modified Wald test are statistically significant at the 1% level for all models. Hence, the Modified Wald test rejects the null hypothesis of groupwise homoskedasticity in all models, confirming the presence of heteroskedasticity in the data. Furthermore, we employed the Wooldridge test to examine the presence of autocorrelation in the residuals of the panel regression models, following Zhou (2013). The results are statistically significant at the 5% level for Models 1 and 2 and at the 1% level for Models 3 and 4. Therefore, the Wooldridge test rejects the null hypothesis of no first-order autocorrelation, indicating the presence of autocorrelation in the panel data. Therefore, the results of these diagnostic tests justify the use of PCSE as the primary estimation technique and FGLS as a robustness estimator.

Table no. 6 – Results of Heteroskedasticity and Autocorrelation Tests

Modified Wald test for groupwise heteroskedasticity				
	Model 1	**Model 2**	**Model 3**	**Model 4**
χ^2	519.21***	470.53***	1830.14***	1529.49***
P-value	0.0000	0.0061	0.0000	0.0004
Accept/Reject	Reject	Reject	Reject	Reject
Wooldridge test for autocorrelation in panel data				
	Model 1	**Model 2**	**Model 3**	**Model 4**
F-statistic	5.870**	5.900**	33.731***	33.817***
P-value	0.0269	0.0265	0.0000	0.0000
Accept/Reject	Reject	Reject	Reject	Reject

Note: The asterisk symbols (*, **, and ***) denote statistical significance at the 10%, 5%, and 1% levels, respectively.

4.1. Primary Regression Results

PCSE is the primary estimation technique employed in this study. Table no. 7 reports the results of the PCSE regression analysis. In Model 1, lnNREC has a positive and statistically significant effect on lnEG, with a coefficient of 0.1840***. This coefficient indicates that a 1% increase in lnNREC is associated with a 0.184% increase in lnEG. The finding suggests that lnNREC plays an important role in promoting lnEG in G20 countries. Therefore, the results support Hypothesis H1, which states that lnNREC has a significant positive effect on lnEG. Ivanovski *et al.* (2021) and Kahia *et al.* (2017) demonstrated that non-renewable energy sources are essential for economic expansion. The use of non-renewable energy sources remains high in G20 countries, many of which have experienced rapid population growth over the past few decades. Consequently, these economies continue to rely heavily on non-renewable energy sources to meet the growing energy demand (Aboueata *et al.*, 2021). In addition, we have

discovered a significant positive moderating role of lnGI (0.2231***) in the effects of lnNREC and lnEG in Model 2. The finding supports Hypothesis (H3a) that lnGI significantly moderates the relationship between non-renewable energy consumption and economic development. According to Onifade *et al.* (2025), lnGI promote sustainable economic development rather than hinder it. Similarly, Wan and Sheng (2022) confirmed the significant positive role of lnGI and suggested that it is an effective means of stimulating lnEG.

Table no. 7 – Results of PCSE Regression Analysis

Variable	Model 1		Model 2	
	Coefficient	p-value	Coefficient	p-value
lnNREC	0.1840*** (0.0317)	0.000	0.3327*** (0.0564)	0.000
lnGI	-0.2859*** (0.0570)	0.000	-2.0571*** (0.4776)	0.000
lnNREC × lnGI		-	0.2231*** (0.0560)	0.000
lnFDI	-0.0062 (0.0049)	0.204	-0.0026 (0.0043)	0.547
lnTO	-0.0464 (0.0863)	0.591	0.1235 (0.0796)	0.121
COVID19	0.4181 (0.2801)	0.136	0.3818 (0.2808)	0.174
_cons	-0.4306 (0.5617)	0.443	-2.3751*** (0.6550)	0.000
Wald chi²	65.05	0.0000	83.14	0.0000
N	228		228	
R-squared	0.1380		0.1633	

Note: The dependent variable is lnEG. The figures in parentheses are the standard errors. The asterisk symbols (*, **, and ***) denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table no. 8 – Results of PCSE Regression Analysis

Variables	Model 3		Model 4	
	Coefficient	p-value	Coefficient	p-value
lnNREC	1.1501*** (0.0088)	0.000	1.2838*** (0.0126)	0.000
lnGI	-0.1770*** (0.0198)	0.000	-1.6239*** (0.1216)	0.000
lnNREC × lnGI	-	-	-0.1836*** (0.0139)	0.000
lnFDI	0.0050*** (0.0010)	0.000	0.0082*** (0.0012)	0.000
lnTO	0.2262*** (0.0327)	0.000	0.3909*** (0.0400)	0.000
COVID19	0.0094 (0.0111)	0.399	-0.0134 (0.0082)	0.104
_cons	10.0174*** (0.2210)	0.000	8.2297*** (0.2724)	0.000
Wald chi²	132946.27	0.000	229563.88	0.000
N	260		260	
R-squared	0.8870		0.8967	

Note: The dependent variable is lnED. The figures in parentheses are the standard errors. The asterisk symbols (*, **, and ***) denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table no. 8 reports the results of the PCSE regression analysis, with lnED as the dependent variable. In Model 3, lnNREC has a positive and statistically significant effect on lnED, with a coefficient of 1.1501***. This coefficient indicates that a 1% increase in lnNREC is associated with a 1.150% increase in CO_2 emissions. The findings suggest that the use of non-renewable energy sources in G20 countries contributes significantly to lnED. Therefore, the results support Hypothesis H2, which posits that lnNREC exerts a significant positive effect on lnED. Our findings align with those of Chien (2022) and Adekoya *et al.* (2024), which highlighted the impact of using non-renewable energy on CO_2 emissions. The total CO_2 emissions by G20 countries increased by 15% from 2010 to 2023 (Ritchie *et al.*, 2023). Fossil fuel combustion generates substantial CO_2 emissions that are harmful to the environment and contribute to global warming (Zhang *et al.*, 2024). The 15.93% increase in fossil fuel consumption among G20 countries has contributed significantly to the rise in global CO_2 emissions (Our World in Data, 2025). Furthermore, our results indicate that lnGI mitigates the environmental impacts of lnNREC. In Model 4, the interaction term has a negative and statistically significant coefficient (-0.1836***), indicating that lnGI weakens the positive relationship between lnNREC and lnED. In other words, higher levels of lnGI mitigate the adverse environmental effects associated with lnNREC. Therefore, the finding supports Hypothesis H3b, which posits that lnGI significantly moderates the relationship between lnNREC and lnED. This result is consistent with Dong *et al.* (2024), who found that carbon emissions are significantly reduced in economies that prioritize lnGI (Shaukat *et al.*, 2026). Furthermore, lnGI can support research and development in cleaner technologies, thereby minimizing the environmental impact of lnNREC (Beşer *et al.*, 2025).

4.2. Conditional Net Effects and Interaction Plots

Table no. 9 presents the conditional effect of lnNREC at low, mean, and high levels of lnGI. The results show that the effect of lnNREC on lnEG increases with lnGI. At a low level of lnGI, the conditional effect is 0.0147. It increases to 0.1728 at the mean level and 0.3309 at the high level. This pattern indicates that lnGI strengthens the positive relationship between lnNREC and lnEG. The effect of lnNREC on lnED shows the opposite pattern. The conditional effect declines from 1.5455 at a low level of lnGI to 1.4154 at the mean level and 1.2853 at the high level. The effect remains positive at all three levels. However, its magnitude decreases as green investment rises. This result suggests that lnGI reduces the harmful environmental effect of lnNREC. Hence, the findings support the moderating role of lnGI in both models. Higher lnGI strengthens the economic effect of lnNREC and weakens its environmental effect.

Table no. 9 – Conditional net effects of lnNREC at different levels of lnGI

Level of lnGI	Value of lnGI	Effect on lnEG	Effect on lnED
Low	−1.4256	0.0147	1.5455
Mean	−0.7168	0.1728	1.4154
High	−0.0080	0.3309	1.2853

Note: Low and high levels represent one standard deviation below and above the mean of lnGI. The conditional effects are calculated from Models 2 and 4 of the PCSE analysis. The interaction terms are statistically significant at the 1% level in both models.

Further, the interaction plots present predicted lnEG and lnED at low and high levels of lnNREC under low and high levels of lnGI. This procedure is applied separately to models of both dependent variables. Figure no. 5 visually supports the net effect results for EG. The slope of lnNREC becomes steeper at a higher level of lnGI. This pattern shows that lnGI strengthens the positive relationship between lnNREC and lnEG. Figure no. 6 visually supports the net effect results for lnED. Although lnED increases with lnNREC at both levels of lnGI, the slope becomes less steep when lnGI is high. This suggests that lnGI mitigates the adverse environmental impact of lnNREC.

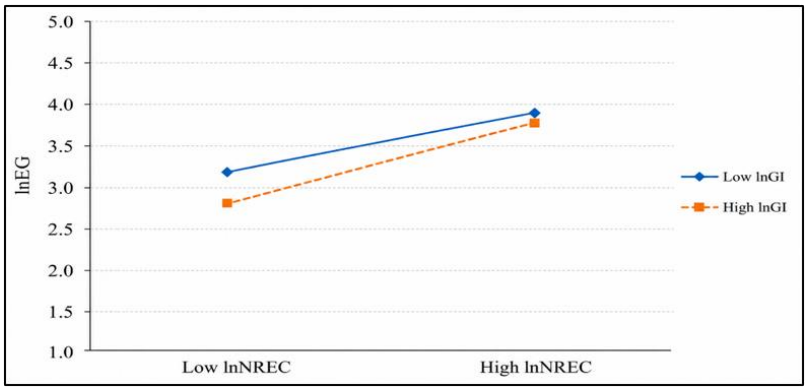

Figure no. 5 – Interaction between non-renewable energy consumption (lnNREC) and green investment (lnGI) on economic growth (lnEG)

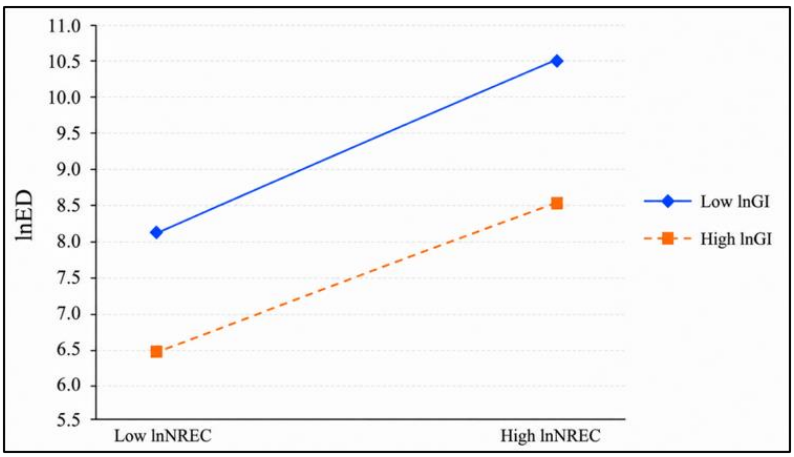

Figure no. 6 – Interaction between non-renewable energy consumption (lnNREC) and green investment (lnGI) on environmental degradation (lnED)

4.3. Endogeneity and Robustness Checks

Tables no. 10 and no. 11 report the findings of the FGLS estimator, which we have used for a robustness check. FGLS regression improves the effectiveness of estimates by

accounting for heteroscedasticity and autocorrelation. However, Lewis and Linzer (2005) highlighted that FGLS not only addresses heteroskedasticity, autocorrelation, and cross-section dependence, but also outperforms PCSE in terms of the precision and accuracy of the estimated parameters (Beck and Katz, 1995). Moreover, the FGLS findings indicate that the signs and significance levels of the coefficients of our study variables' relationships align with those of our primary estimator, PCSE. Therefore, our results are stable and robust across the various estimators used.

Table no. 10 – Results of FGLS Regression Analysis

Variables	Model 1		Model 2	
	Coefficient	p-value	Coefficient	p-value
lnNREC	0.1840*** (0.0548)	0.001	0.3327*** (0.0782)	0.000
lnGI	-0.2859*** (0.0755)	0.000	-2.0573*** 0.6777	0.002
lnNREC × lnGI	-	-	0.2231*** (0.0848)	0.009
lnFDI	-0.0062 (0.0092)	0.497	-0.0026 (0.0092)	0.776
lnTO	-0.0464 (0.1621)	0.775	0.1235 (0.1723)	0.474
COVID19	0.4181*** (0.1156)	0.000	0.3818*** (0.1147)	0.001
_cons	-0.4306 (0.9843)	0.662	-2.3751* (1.2195)	0.051
N	228		228	
Wald chi²	36.49	0.0000	44.51	0.0000

Note: The dependent variable is lnEG. The figures in parentheses are the standard errors. The asterisk symbols (*, **, and ***) denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Table no. 11 – Findings of FGLS Regression Analysis

Variables	Model 3		Model 4	
	Coefficient	p-value	Coefficient	p-value
lnNREC	1.1501*** (0.0262)	0.000	1.2838*** (0.0368)	0.000
lnGI	-0.1770*** (0.0348)	0.000	-1.6239*** (0.2935)	0.000
lnNREC × lnGI	-	-	-0.1836*** (0.0370)	0.000
lnFDI	0.0050 (0.0045)	0.266	0.0082* 0.0043	0.057
lnTO	0.2262*** (0.0741)	0.002	0.3909*** (0.0782)	0.000
COVID19	0.0094 (0.0522)	0.857	-0.0134 (0.0501)	0.789
_cons	10.0174*** (0.4492)	0.000	8.2297*** (0.5605)	0.000
N	260		260	
Wald chi²	2039.94	0.0000	2145.71	0.0000

Note: The dependent variable is lnED. The figures in parentheses are the standard errors. The asterisk symbols (*, **, and ***) denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Another critical challenge is endogeneity, which arises when an independent variable is correlated with the error term in a model. Such a correlation can lead to biased estimation results and compromise the reliability of the study's conclusions (Ullah *et al.*, 2018; Barros *et al.*, 2020). To address this concern, we implemented a dynamic regression model referred to as the GMM. This strategy is better than alternative dynamic regression techniques when the dataset is contemporaneous (N > T). Instead of using the difference GMM estimator, this study employed the system GMM estimator, as it yields more robust results and offers superior treatment of endogeneity concerns (Zarra-Nezhad *et al.*, 2014). Table no. 12 reports the results of the one-step system GMM estimation. The estimated coefficients exhibit signs consistent with those obtained using the PCSE and FGLS estimators, thereby confirming the robustness of the main findings.

Table no. 12 – Results of One-Step System GMM Regression

Variables	Model 1	Model 2	Model 3	Model 4
L1. lnEG	0.3390*** (0.1113)	0.3377*** (0.1119)	-	-
L1. lnED	-	-	0.7086*** (0.1196)	0.6853*** (0.1173)
lnNREC	0.1843*** (0.0967)	0.2618** (0.1045)	0.3435*** (0.1250)	0.4115*** (0.1195)
lnGI	-0.2624 (0.1846)	-1.3655 (1.4210)	-0.0659 (0.0419)	-0.5235* (0.2820)
lnNREC × lnGI	-	0.1366*** 0.1689	-	-0.0579** (0.0328)
lnFDI	-0.0039*** (0.0067)	-0.0025*** (0.0070)	0.0017** (0.0011)	0.0027*** (0.0010)
lnTO	0.0125 (0.2205)	0.0733 (0.2445)	0.0751 (0.0615)	0.1296 (0.0826)
COVID19	0.0837 (0.0945)	0.0551 (0.0831)	-0.0012 (0.0064)	-0.0079 (0.0075)
Instruments	19	20	19	20
AR (1)	0.001	0.001	0.005	0.007
AR (2)	0.954	0.959	0.497	0.185
Sargan test	24.03	24.00	111.46	105.18
Prob > chi²	0.020	0.020	0.000	0.000

Note: The figures in parentheses are the standard errors. The asterisk symbols (*, **, and ***) denote statistical significance at the 10%, 5%, and 1% levels, respectively.

5. CONCLUSION AND POLICY IMPLICATIONS

G20 nations are among the world's most dynamic and rapidly developing economies. They face substantial environmental degradation as a result of using non-renewable energy resources to achieve economic growth. Therefore, we have examined the economic and environmental impacts of non-renewable energy consumption in G20 countries. This study examined panel data from G20 countries covering the period from 2010 to 2023. Using the PCSE and FGLS estimators, the results indicate that non-renewable energy consumption exerts a significant positive effect on the economic growth of G20 countries. The main reason is that most G20 nations still rely on non-renewable energy resources to support their economic expansion. A 15.93% increase in total fossil fuel consumption was recorded

across G20 countries between 2010 and 2023 (Our World in Data, 2025). Furthermore, we found a positive link between non-renewable energy and environmental deterioration. We noted that a 1% increase in non-renewable energy consumption is linked with a 1.150% increase in CO_2 emissions. Consequently, the total CO_2 emissions by G20 countries increased by 15% from 2010 to 2023 (Ritchie *et al.*, 2023). These CO_2 emissions are not only damaging the environment of G20 nations but also that of the entire world.

Further, we found that the moderating influence of green investment on the relationship between non-renewable energy consumption and economic development is positive. Green investment is an efficacious means of stimulating economic expansion in G20 nations. We found that integrating economic activities with green initiatives has generated positive outcomes in G20 economies. Secondly, we found that green investment negatively moderates the relationship between non-renewable energy consumption and environmental degradation. The G20 countries have always faced environmental issues for decades due to their excessive reliance on fossil fuels. Green investments have become imperative for G20 countries due to their heavy reliance on non-renewable energy sources. Such environmentally sustainable investments can promote economic growth while simultaneously contributing to environmental preservation. Given the substantial CO_2 emissions associated with the use of non-renewable energy sources, these countries should allocate a portion of their budgets to environmental conservation initiatives.

Therefore, policymakers in G20 nations must couple economic initiatives with green investments. Further, huge emissions of CO_2 can only be controlled by allocating a part of the country's budget to environmental conservation initiatives. Moreover, policymakers ought to allocate resources and support the adoption of green technologies for the production of goods and services. It is especially crucial for developing G20 nations and those that have massive population growth like India and China. Their economic growth initiatives through non-renewable sources must be supplemented by green investments. These investments in eco-friendly technologies can control the potential CO2 emissions from non-renewable energy resources and ultimately protect the environment.

Despite the robustness of the findings, this study has several limitations. First, the panel dataset covers a relatively short time span, which may not fully capture long-term structural trends or the gradual effects of policy interventions. Second, the study relies on aggregate panel data for G20 countries. The results could not account for country specific relationships among variables, as there are significant differences among member countries of the G20 in terms of geographical characteristics, economic structures, econometric conditions and energy consumption patterns. Finally, because the findings are based exclusively on G20 economies, their direct applicability to low- and middle-income countries with weaker institutional and financial capacities may be limited. Future research could address these limitations by examining individual G20 countries or groups of countries with similar economic and institutional characteristics.

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