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Economic Growth, Climate Change and Clean Energy in a Post-COVID Era

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ABSTRACT

This study analyzes how clean technology, including electric vehicles, clean cooking and lighting fuels, renewable energy, and renewable electricity generation, might assist to reduce climate change and promote sustainable development. These goals include improving health and well-being (SDG-3), ensuring clean water and sanitation (SDG-6), promoting industry, innovation, and infrastructure (SDG-9), combating climate change (SDG-13), developing sustainable cities and communities (SDG-11), protecting life below water (SDG-14), and preserving life on land (SDG-15). The study employed data from the World Development Indicators (WDI) and the Generalized Method of Moments (GMM). According to the research, the deployment of clean energy technology has the ability to drastically lessen the impact of climate change, ensuring the long-term survival of the environment and ecosystems on a worldwide scale. The move from gasoline-powered vehicles to electric vehicles propelled by renewable energy sources has the potential to considerably cut carbon emissions related with transportation. Furthermore, installing energy-efficient appliances and lighting can efficiently minimize energy consumption and the carbon footprint connected with home power usage.

Keywords: Carbon Footprints, Climate Change, Clean Energy, Electric Vehicles, Sustainable Development Goals
JEL Classifications: Q01, Q42, Q53

1. INTRODUCTION

Greenhouse gas emissions have had a considerable impact on pollution and climate change since the middle of the twentieth century (Degbedji et al., 2024; Guo et al., 2025; Osabohien et al., 2024). Automobile traffic has emerged as a substantial contributor to world emissions, accounting for around 57% and 14% of total CO and CO_2 emissions, respectively (Adeleye, Daramola, Onabote & Osabohien, 2021; Fan et al.,2023; Matthew et al., 2018). These emissions influence biodiversity, human well-being, ecosystems, and the environment, with direct and indirect effects for human health (Gershon et al., 2020; Matthew et al., 2020; Mohamed et al., 2024; Osabohien et al., 2020; Requia et al. 2018; Urhie et al., 2020). Carbon emissions directly harm human health by changing the respiratory system, resulting in asthma, headaches, disorientation, and lung cancer (Fajersztajn et al., 2013; Jaaffar et al., 2024; Osabohien et al., 2021; Raihan et al., 2023; Sahan et al., 2025; Svendsen et al., 2012).

Carbon emissions considerably boost the incidence of diseases like diabetes. The significant increase in carbon emissions, which endangers the environment (Adeleye, Osabohien, Lawal, De Alwis, 2021; Ashraf & Javed, 2023; Imeokparia et al., 2023; Onabote et al., 2021; Osabohien et al., 2023; Yin et al., 2022), complicates achieving sustainable development goals such as good health and wellbeing (SDG3), life below water (SDG14), and life on land (SDG15). To combat these toxins, there is a global push for clean technologies, including renewable energy for cooking and lighting, electric vehicles, and solar systems. However, climate change has the potential to exacerbate air pollution and hasten the onset of respiratory disorders. The terrible impacts of carbon emissions on the environment and human health have pushed the use of clean technology, such as electric autos (Jaaffar et al., 2018).

Electric vehicles are a more efficient and environmentally advantageous choice since they reduce health concerns and carbon emissions, which affect the environment and ecosystems. According to the Global EV Outlook (2020), electrification of transportation is vital for cutting air pollution and greenhouse gas emissions. Data on global electric car sales from 2020 demonstrate that sales of electric vehicles have constantly grown since 2010, thanks to stringent government targets. In 2019, electric vehicle sales reached a new high of 2.1 million.

According to the International Energy Agency (IEA, 2020), the global electric vehicle fleet has expanded by 40% since 2018, totaling 7.2 million vehicles. China dominated the international electric car market with around 47%, with the United States and Canada contributing <10% each and Europe accounting for 25%. The migration to electric vehicles is vital for minimizing future air pollution and greenhouse gas emissions while also helping governments reach their energy diversification targets (Global EV Outlook, 2020). Renewable energy has a major impact on both the environment and climate change (Jaaffar et al., 2019).

Developing sustainable environmental guidelines based on a number of criteria such as electricity generating profiles, power plant locations, and types of electric vehicles. However, a rise in electric vehicle sales and inventory is necessary. The implementation of novel technology to minimize carbon emissions and promote health may be delayed if a country relies significantly on nonrenewable energy sources that release more CO_2. Helmers et al. (2017) evaluated the emissions from power generation for Battery Electric Vehicles (BEVs) in Germany and China. Their research found that coal-based electricity in China produced around 215 g/km of CO_2 to power BEVs, compared to 113 g/km on the German grid. Nonetheless, the relationship between clean technology and carbon footprints, which have a substantial impact on climate change and the development of a sustainable ecosystem, has gotten little attention in recent study.

Despite extensive study in this sector, knowledge gaps still remain. For example, whilst earlier research has explored the relationship between renewable energy and economic growth, few have looked into how COVID-19 influences this relationship. This is crucial as the epidemic has disrupted global supply lines, causing economic downturns and impeding the development of renewable energy technology. As a result, additional research is required to better understand the dynamic influence of COVID-19 on the junction of renewable energy and the economy. Additional research is required to investigate the social and environmental ramifications of renewable energy adoption in developing countries.

While renewable energy has considerable economic benefits and can help battle climate change, its implementation must embrace social equality and sustainability to avoid severe social and environmental effects. These research gaps underline the necessity of investigating the interaction between renewable energy, the economy, and climate change, particularly in view of the emerging consequences of COVID-19. Such research can assist influence government initiatives and facilitate long-term economic recovery following a pandemic. The goal of this study is to conduct a scientific investigation of the influence of clean technology adoption on ecological footprints, with a focus on the potential for carbon neutrality. The study is split into five sections: an introduction, a literature review in Section 2, methodology in Section 3, presentation and discussion of results in Section 4, and concluding remarks in Section 5.

2. LITERATURE REVIEW

2.1. Mitigation Actions and Their Assessment

In their literature analysis, Akkermans et al. (2023) created an integrated assessment model to evaluate solutions for lowering greenhouse gas emissions in Tajikistan. While not expressly addressing the COVID-19. The study, which focused on the confluence of renewable energy, the economy, and climate change, provided insights into strategies for decarbonizing a developing country's energy sector. It stressed the relevance of policy interventions such as carbon pricing, renewable energy subsidies, and energy efficiency regulations in expanding the use of clean energy and lowering emissions. Sebos et al. (2020) stressed the need of incorporating stakeholders in planning and implementing mitigation initiatives.

Shaikh et al (2023) looked at how the COVID-19 pandemic influenced the profitability and market value of renewable energy enterprises. Their findings demonstrated an unanticipated tendency of increased market value for clean energy firms during the epidemic. Furthermore, the investigation indicated a negative association between revenue changes and firm market capitalization as financial indicators between 2020 and 2021. Data reveal that businesses in the TRBC Industry Name Renewable Fuels witnessed an average gain in market value. The analysis makes use of statistical approaches such as covariance and correlation. The data showed that, while revenue declined by 2%, the market value of renewable energy companies increased by 150%.

Ye et al. (2022) looked at how green finance trends, such as green loans, investments, securities, and corporate social responsibility (CSR), affected renewable energy investment reporting. Their findings demonstrated a strong positive association between renewable energy investment in the selected developing country and variables such as green credit, investments, securities, CSR reporting, and economic growth.

De Marco et al. (2021) studied the potential benefits of increased renewable energy generation for the Brazilian economy and its role in reducing the recession caused by the SARS-CoV2 outbreak. The study employed machine learning techniques, such as Long Short-Term Memory (LSTM) models, with Brazilian economic data to estimate the economic impact of renewable energy. The data reveal that clean energy sources outperformed other energy components, resulting in quicker GDP growth.

Dissanayake et al. (2023) looked analyzed the relationship between the usage of renewable and non-renewable energy sources, CO_2 emissions, and economic growth in 152 countries classified as developed, developing, Least Developed Countries (LDCs), and Economies in Transition between 1990 and 2019. Granger causality was employed to examine these relationships. Except for Economies in Transition, the analysis indicated no Granger-causal connection between GDP and renewable energy consumption.

2.2. COVID-19 Pandemic Effect and Economic Effect of Mitigation Actions

Stamopoulos et al. (2021) evaluated the possible influence of renewable energy investments on economic growth, using Greece's National Energy and Climate Plan as a case study. The authors suggested that shifting to renewables may offer new job opportunities, cut energy imports, and increase energy security, all of which would promote economic growth. The study employed a computable general equilibrium (CGE) model to simulate multiple scenarios, including a baseline scenario with no renewable energy investments and six scenarios with increasing degrees of investment in renewables. The findings suggested that such investments might have a good economic impact, including raising GDP and employment. However, the amount of these effects varied according to the quantity of investment, technical deployment, and legislative frameworks.

Le et al. (2020) evaluated the relationship between energy use, economic development, and greenhouse gas emissions using panel data from 102 countries covering 1996 to 2012. Separate evaluations were done to analyze the impact of renewable and nonrenewable energy sources. The findings demonstrated that both renewable and non-renewable energy consumption had a substantial impact on global income levels, showing that expanding the use of renewable energy could increase economic growth (Lapinskienė et al., 2017). While non-renewable energy usage resulted in a considerable increase in emissions across countries of varied economic statuses, the study indicated that adopting renewable energy sources lowered emissions in wealthy countries but not in poorer countries.

Inglesi-Lotz (2016) used panel data approaches to examine the economic consequences of bringing renewable energy into the energy mix. The findings demonstrated that embracing clean energy or expanding its part of the overall energy portfolio improved economic development, resulting in policy gains for both countries' economy and the environment. These findings are similar with Imeokpara et al.'s (2023) research, which indicated that oil export profits and yearly oil production volumes supported human capital development and poverty reduction in some African oil-exporting countries.

Khoa (2022) looked into the relationship between socioeconomic advancement and environmental degradation from 1990 to 2018. While greenhouse gasses were discovered to have a long-term causal influence, feedback factors functioned more swiftly. The analysis indicated a close relationship between the variables mentioned. Furthermore, variance decomposition analysis revealed that GDP accounted for between 3% and 14% of future changes in greenhouse gas emissions; energy consumption fluctuated between 3% and 14%; clean energy utilization ranged from 1% to 3.4%; tourism contributed 4.2% to 10% of future variations; and improvements in access to water, sanitation, and power accounted for 33.3%, 1.12%, and 2.01% of future fluctuations, respectively.

Apadogiannaki et al. (2023) carry out a study on the influence of the COVID-19 epidemic on the carbon footprints of two research endeavors. The authors utilized a life cycle assessment (LCA) technique to analyze carbon emissions from transportation, electricity consumption, and garbage generation before and after the outbreak. The studies found that carbon emissions fell considerably throughout the outbreak, owing mostly to lower travel-related emissions. Progiou et al. (2022) evaluated the impact of the COVID-19 outbreak on air pollution levels in Athens, Greece Eroğlu (2021). The study collected data from air quality monitoring sites to investigate how pollutant concentrations changed during the outbreak. The results demonstrated a considerable reduction in air pollution levels, particularly nitrogen dioxide (NO_2) and particulate matter (PM10), as a result of reduced traffic and industrial activity during lockdowns.

2.3. Synergies between Mitigation and Adaptation: Stakeholder Analysis and Climate Change

Kyriakopoulos and Sebos (2023) offered an outline of how mitigation and adaptation measures could increase climate neutrality and resilience. The authors stressed the significance of coordinated climate policies that incorporate both reduction and adaptation options for better impact and long-term sustainability. The study explored a number of approaches for lowering greenhouse gas emissions, including renewable energy sources, energy efficiency improvements, and carbon capture and storage projects. Furthermore, adaption options such as climate-resilient agriculture, water resource management, and urban design were studied. Ioanna et al. (2022) did a stakeholder analysis on climate change adaptation projects in Greece. The study underscored the significance of knowing the roles and views of different stakeholders for planning and executing effective adaptation strategies. A participative approach was utilized to identify and study four main stakeholder groups involved in climate change adaptation projects in Greece.

Madaleno et al. (2022) explored the links between green finance, renewable energy deployment, environmental conservation, and green technology acceptability. The researchers ran a time-varying causality test utilizing daily data from July 31, 2014 to October 12, 2021. The findings demonstrated bidirectional causal links between these factors, which altered over time. The impact of green money on sustainable energy has fluctuated, particularly during the COVID-19 pandemic. However, the overall link between clean energy and green financing indicated Higher unpredictability and connection, highlighting the necessity of developing clean energy in expanding green finance investments.

Dogan et al. (2023) used the "TVP-VAR" connectivity framework to explore the interaction between renewable energy sources and the environment, using daily data from August 1, 2014 to February 4, 2022. The data demonstrated that solar and biofuel played key roles in propagating net shocks among renewable sources, with global carbon benefiting the most from these shocks. Wind and solar energy were discovered to have a major impact on world carbon levels. Despite the strong link between clean energy and the environment, economic disturbances such as oil crises and pandemics may have an impact on this relationship, with fuel cells identified as a major source of shocks during the COVID-19 pandemic.

Seboes et al. (2015) conducted an online poll to analyze stakeholder opinions toward the necessity of planning and implementing adaption methods to alleviate the effects of climate change. While stakeholders recognized the benefits of these initiatives, they also recognized the limitations of present choices for coping with the long-term implications of climate change in Greece. Kasperowicz et al. (2020) employed the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) estimators to study the long-term association between renewable energy use and economic growth across 29 European countries. Their investigations demonstrated a positive, long-term equilibrium link between economic growth and renewable energy consumption, demonstrating that using renewable energy boosts economic growth.

Ntanos et al. (2018) evaluated the relationship between renewable energy use and economic growth in 25 European nations, as defined by GDP per capita. The researchers employed the autoregressive distributed lag (ARDL) model to establish interconnectivity across all variables, indicating a long-term relationship between GDP, renewable and non-renewable energy consumption, gross fixed capital creation, and labor force. Similarly, Soava et al. (2018) examined Eurostat data to assess the causal link between economic development and renewable energy consumption in 28 EU member states. The study examines into the influence of the COVID-19 epidemic on the carbon footprints of two research projects. The authors utilized a life cycle assessment (LCA) approach to analyze carbon emissions from transportation, electricity consumption, and garbage generation before and after the outbreak. The findings revealed that carbon emissions fell considerably during the outbreak, owing mostly to lower travel-related emissions.

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Ioanna et al. (2022) conducted a stakeholder research for climate change adaptation programs in Greece. The study stressed the significance of knowing the responsibilities and views of numerous stakeholders for planning and implementing effective adaption methods. A participative approach was utilized to identify and examine four primary stakeholder groups involved in climate change adaptation projects in Greece. Madaleno et al. (2022) explored the links between green finance, renewable energy deployment, environmental conservation, and green technology acceptability. The researchers conducted a time-varying causality test with daily data from July 31, 2014 to October 12, 2021. The results demonstrated bidirectional causal links between these factors, which altered over time. The impact of green money on sustainable energy has evolved, especially during the COVID-19 pandemic. However, the overall link between clean energy and green financing indicated each nation in the panel revealed unidirectional Granger causation between these two macroeconomic parameters.

Eroglu et al. (2021) did a thorough analysis of the available literature to investigate the consequences of the Covid-19 epidemic on the environment and the renewable energy industry. The study promises to provide vital insights for future research in environmental and renewable energy studies. Adebayo et al. (2020) discovered that changes in renewable energy production affect CO_2 emissions, as do fluctuations in fossil fuel energy output. Furthermore, oscillations in COVID-19 occurrences were observed to coincide to changes in CO_2 emissions. The study also established a causal link between renewable energy, fossil fuels, and COVID-19.

3. DATA AND METHODOLOGY

3.1. Data Sources and Description of Variables

This research combines panel data from the World Development Indicators (WDI) and the International Energy Agency (IEA), covering the years 2016 to 2021. The study looks into data from 27 countries chosen based on availability across the relevant time span to analyze the evolving impact of the COVID-19 pandemic. The study includes the following countries: Australia, Belgium, Brazil, Canada, Chile, China, Denmark, Finland, France, Germany, Greece, India, Italy, Japan, Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, South Africa, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

The variables in the study include a dependent measure of climate change (measured as total greenhouse gas emissions in kilotons of CO_2 equivalent) from the World Development Institute. Furthermore, independent indicators from the WDI include clean technology metrics such as renewable energy use (as a fraction of total final energy consumption) and access to clean fuels and cooking methods (as a percentage of the population). The International Energy Agency provided us with data on electric vehicles (EVs). Control variables included economic growth (measured by GDP per capita as an annual percentage) and

Table 1: Variables, measurement and sources

Variable name	Measurement	Source	Expectations
Climate change	Total greenhouse gas emissions (kt of CO2 equivalent)	WDI	Not Applicable
Electric vehicles	Quantity of EVs	IEA	Negative (−)
Renewable energy consumption	Renewable energy consumption (% of total final energy consumption)	WDI	Negative (−)
Clean fuels	Access to clean fuels and technologies for cooking (% of population)	WDI	Negative (−)
Economic growth	GDP growth per capita (annual %)	WDI	Positive/Negative (+/−)
Population growth	Population growth (annual %)	WDI	Positive/Negative (+/−)

WDI means World Development Indicators; IEA means International Energy Agency
Source: The Authors' Compilations

population increase (also expressed as an annual percentage). Table 1 provides a detailed summary of the factors evaluated in this study.

3.2. Model Specification and Estimation Techniques

To address concerns about endogeneity and reverse causality, this study employs two key approaches: Pooled ordinary least squares (POLS) and the system Generalised Method of Moments (GMM). The independent variable coefficients and the intercept term in the POLS approach are constant over time and space. It is assumed that all independent factors are exogenous and non-stochastic, allowing for the evaluation of their impact on the dependent variable over many temporal and geographical dimensions (Lee, 2007; Matthew et al., 2022). While POLS offers some advantages, such as simplicity, it does have limitations. It fails to address heterogeneity issues (Adeleye et al., 2020) and cannot account for country-specific implications (Arellano and Bover, 1995; Aggarwal and Padhan, 2017; Lin and Lee, 2010). Equation 1 describes the POLS estimation technique.

$$lnCFP_{it} = \beta_0+\beta_1 lnCT'_{it}+\beta_2 lnZ'_{it}+\mu_{it} \quad (1)$$

Where $lnCFP_{it}$ denotes the natural logarithm of the proxy for climate change; β_0 is the intercept term whereas β_1, and β_2 are the coefficients of the explanatory variables. In addition, $lnCT'_{it}$ reflects the natural logarithm of the covariate of clean technology such as electric vehicles, renewable energy usage and access to clean fuels and technologies for cooking. Similarly, lnZ'_{it} indicates the natural logarithm of the covariate of the control variables such as economic growth (GDP growth per capita (annual %)) and population growth (annual %).

The disturbance term is denoted by μ, where i is the nation ID ranging from 1 to 22 and t is the time period ranging from 1 to 17. The GMM approach is used to bypass the POLS constraints. When faced with endogeneity, GMM is regarded to be more dependable and consistent than POLS (Arellano and Bond, 1991; Woodridge, 2010). Equation (1) outlines the GMM model, which is based on the theoretical framework and literature of Baltagi and Baltagi (2008) and Roodman (2006).

To address endogeneity and reverse causation concerns, this work combines two essential approaches: pooled ordinary least squares (POLS) and the system Generalised Method of Moments (GMM). The POLS technique implies that all independent factors are exogenous and non-stochastic, allowing for an assessment of their impact on the dependent variable spanning various time periods and geographical locations. However, POLS have shortcomings, including a failure to handle heterogeneity issues and country-specific implications. When endogeneity is present, the GMM methodology is more dependable and consistent than other methods. Equation 1 offers the GMM model, which is based on the conceptual framework and literature of Baltagi and Baltagi (2008) and Roodman (2006).

$$lCC_{it} = \phi+\rho lCFP_{it-1}+\vartheta lCT_{it}+\phi lZ'_{it}+v_{it},\ i = 1,2\ldots,I;\ t = 1,2,\ldots,T \quad (2)$$

In this equation, lCC_{it} represents climate change i (i = 1,2…,N) at time t (t = 2,3,…,T) ϕ denotes the intercept, $\rho lCFP_{it-1}$ is the first lag of climate change with coefficient ρ, lCT_{it} it captures the covariate of clean technology with coefficient ϑ, and $\phi lZ'$itis the covariate of control variables with coefficient ϕ (ϕ=1,2,3…N). To address the issue of endogeneity and reverse causation, the study developed a system GMM.

In the case of strong endogeneity, the two-stage Least Squares (2SLS) technique may have been examined. However, 2SLS often generates poor estimates of heteroscedasticity. In these circumstances, the Generalized Method of Moments (GMM) is more successful. System GMM estimators are particularly useful when the independent variables are not totally exogenous. Fixed effect estimators are useless in such instances because of the relationship between the mean of the lagged dependent variable and the idiosyncratic error component. This issue is especially critical in dynamic panel data models with short time periods and a large number of individual units (Nickell, 1981).

The model employs the natural logarithm of a climate change proxy ($\rho lCFP_{it-1}$) as its dependent variable. The independent variables include the natural logarithm of a clean technology index (ϑlCT_{it}), which measures components including electric car uptake, renewable energy utilization, and availability of clean fuels and technologies. The model accounts for economic growth (GDP per capita) and population increase ($\phi lZ'_{it}$ t).

Due to the possibility of endogeneity (where the independent variables could be influenced by the dependent variable), the study used a Generalized Method of Moments (GMM) estimation. GMM is recommended over traditional Ordinary Least Squares (OLS) because it generates more consistent and dependable findings in the face of endogeneity. The GMM model is presented in Equation (3):

$$lCC_{it} = \phi+\rho lCFP_{it-1}+\vartheta lCT_{it}+\phi lZ'_{it}+v_{it} \quad (3)$$

This equation captures the impact of lagged climate change $\rho lCFP_{it-1}$, clean technology ϑlCT_{it}, and control variables $\phi lZ'_{it}$

on current climate change lCC_{it}. While the Two-Stage Least Squares (2SLS) technique could be used to handle endogeneity, it is known to provide inaccurate estimates when heteroscedasticity exists. GMM, on the other hand, is more efficient and well-suited to dynamic panel data models, particularly when dealing with non-strictly exogenous variables and short time periods. The application of system GMM explicitly eliminates concerns about endogeneity and reverse causality. This approach offers more reliable and robust estimations of the link between climate change and clean technology uptake.

4. RESULTS AND DISCUSSION

4.1. Summary Statistics

Table 2 summarizes the statistical characteristics of the variables Climate Change (CFP), Electric Vehicles (EV), Renewable Energy Consumption (REC), Clean Fuels (CF), Economic Growth (GDPgr), and Population Growth (POPgr) for the entire sample, as well as for the periods preceding and following COVID-19. The average greenhouse gas emissions for the entire dataset were 1,142,194 kt, demonstrating a constant amount of emissions across the sample. A study of emissions before, during, and after COVID-19 indicated that the average emissions during COVID (1,151,132 kt) exceeded those before COVID (1,133,255 kt). Furthermore, the lowest (43,200 kt) and maximum (12,700,000 kt) emissions occurred during the COVID era. The total sample had an average of 65,189 electric vehicles, demonstrating that this method of transportation is frequently used. Analysis of the pre- and post-COVID periods found that the average number of electric vehicles during COVID (98,673.48) outweighed those before COVID (31,704.53). The pre-COVID period had the fewest electric vehicles (22) and the most (2,700,000).

The average renewable energy usage in the sample was 21.81114%. This means that on average, 21.81114% of the energy consumed is renewable. A comparison of pre- and post-COVID eras found that the average renewable energy consumption during COVID (22.25278%) was bigger than before (21.36951%). Notably, renewable energy consumption was lowest (2.55%) prior to COVID and biggest (62.37%) during COVID.

The total sample had an average percentage of access to clean fuels of 96.40988%, demonstrating broad access to clean cooking fuels and technologies. A comparison of the pre-COVID and post-COVID eras found that the average availability of clean fuels during COVID (96.72963%) surpassed the pre-COVID period (96.09012%). The pre-COVID period had the least access to clean fuels (51.4%), whereas both the pre-COVID and COVID periods had the maximum availability (100%).

The average rate of economic growth throughout the sample was 1.695711%, meaning that economies expanded by 1.695711% overall. When comparing the pre-COVID and post-COVID periods, it was determined that the average rate of economic growth before COVID (2.50166%) was larger than that during COVID (0.8897611%). Furthermore, the COVID period had both the slowest (−11.32544%) and fastest (11.66822%) rate of economic growth. The average rate of population growth across

Table 2: Descriptive statistics of the variables

Variable	Aggregate		Pre-COVID		During-COVID	
	Mean (SD)	Min (Max)	Mean (SD)	Min (Max)	Mean (SD)	Min (Max)
Climate change	1142194 (2527877)	43200 (1.27e+07)	1133255 (2486334)	46580 (1.25e+07)	1151132 (2584217)	43200 (1.27e+07)
Electric Vehicles	65189.01 (247521.5)	22 (2700000)	31704.53 (110075.1)	22 (820000)	98673.48 (330019.1)	92 (2700000)
Renewable Energy Consumption	21.81114 (14.87503)	2.55 (62.37)	21.36951 (14.83016)	2.55 (61.09)	22.25278 (14.999)	3.27 (62.37)
Access to clean fuels and technology	96.40988 (9.190715)	51.4 (100)	96.09012 (10.17716)	51.4 (100)	96.72963 (8.137117)	63.9 (100)
Economic growth	1.695711 (3.71928)	−11.32544 (11.66822)	2.50166 (1.733872)	−3.275917 (8.256306)	0.8897611 (4.849469)	−11.32544 (11.66822)
Population growth	0.5613679 (0.5815877)	−1.153028 (2.246032)	0.6507979 (0.5859512)	−0.415913 (2.246032)	0.4719378 (0.5667295)	−1.153028 (2.204789)

the sample was 0.5613679%, meaning that populations increased by 0.5613679% overall. When the pre-COVID and post-COVID periods were examined, it was determined that the average rate of population growth previous to COVID (0.6507979%) was larger than that during the COVID period (0.4719378%). Furthermore, the COVID period had the lowest rate of population increase (−1.153028%), while the highest (2.246032%) was recorded prior to COVID.

4.2. Pooled Ordinary Least Squares (POLS) Estimation Results

The results in Table 3 reveal a substantial and statistically significant association between electric vehicles and overall greenhouse gas emissions across the sample. This discovery contradicts Hao et al.'s (2017) findings on electric vehicles and greenhouse gas reduction in China. Fuinhas et al. (2021) claim that extensive planning is required to build a negative link between these elements. According to the statistics, an increase in the number of electric vehicles in the sample is connected with an increase in greenhouse gas emissions, which exacerbates the impact of climate change. The pooled ordinary least squares (POLS) estimate for the full sample shows that each percentage increase in the number of electric vehicles produces a 0.2% increase in greenhouse gas emissions.

The POLS estimations also reveal that electric vehicles had a favorable and statistically significant influence on greenhouse gas emissions both before and after COVID. This means that a percentage increase in the number of electric vehicles before and after COVID will result in a 0.19% and 0.22% rise in total greenhouse gas emissions, respectively, contributing to climate change. Furthermore, Table 3 reveals that the availability of clean fuels had a negative and statistically significant influence on total greenhouse gas emissions across the entire sample, which is consistent with Tariq et al.'s (2023) findings. The POLS estimate for the full sample anticipated that an increase in the availability of clean fuels would result in a 7.87% reduction in greenhouse gas emissions.

Furthermore, the POLS estimates demonstrate that the population's access to clean fuels had a negative and statistically significant influence on greenhouse gas emissions before to and following COVID. This illustrates that increasing access to clean fuels before and during COVID will result in a 6.83% and 10% reduction in world greenhouse gas emissions, therefore reducing climate change. The findings also show that renewable consumption had a negative and statistically significant impact on total greenhouse gas emissions for the entire sample, which is consistent with Chien et al.'s (2022) research on the role of renewable energy and urbanization in reducing greenhouse gas emissions in major Asian countries.

These findings imply that increasing overall renewable energy consumption across the dataset is connected with a reduction in greenhouse gas emissions, thereby contributing to climate change mitigation. According to the pooled ordinary least squares (POLS) estimate for the full sample, each percentage point increase in renewable energy consumption is predicted to result in a 0.92% reduction in greenhouse gas emissions.

Furthermore, the results of the POLS estimations demonstrate that the link between renewable energy consumption and greenhouse gas emissions was consistently negative and statistically significant both before and during the COVID-19 period. This reveals that increasing renewable energy consumption will yield in a 0.87% reduction in overall greenhouse gas emissions prior to COVID-19 and a 0.95% reduction during the pandemic, therefore positively aiding to climate mitigation efforts.

Table 3 revealed that a gain in GDP per capita had a negative influence on total greenhouse gas emissions across the sample, however this was not statistically significant. This shows a potential relationship in which higher levels of economic growth could lead to fewer climate change consequences in the total sample. However, due to a lack of statistical significance, no definite conclusions concerning this association can be reached. Similarly, the POLS estimate found a negative but statistically insignificant association both before and after the COVID-19 outbreak began.

Furthermore, Table 3 demonstrated that population expansion had a negative impact on total greenhouse gas emissions in the overall dataset, albeit not statistically significant. This shows that a rise in population rates could help to minimize climate change over the entire sample. However, similar to the impact of GDP per capita growth, the absence of statistical significance restricts the strength of inferences formed from this link. Furthermore, the POLS estimate indicated a positive but statistically negligible correlation prior to the COVID-19 era and a negative but statistically insignificant link during the COVID-19 time.

4.3. GMM Estimation Results

Table 4 demonstrates that electric vehicles had a positive and statistically significant influence on overall greenhouse gas

Table 3: Pooled ordinary least squares estimates

Variable	Aggregate	Pre-COVID	During-COVID
logEV	0.1984968*** (0.000)	0.1929288*** (0.002)	0.2216239** (0.012)
logCF	−7.863999*** (0.000)	−6.826425*** (0.000)	−9.999588*** (0.000)
logREC	−0.9171569*** (0.000)	−0.8661039*** (0.000)	−0.953495*** (0.001)
logGDPgr	−0.1378317 (0.447)	−0.0716247 (0.813)	−0.1481122 (0.534)
logPOPgr	−0.0262217 (0.828)	0.000203 (0.999)	−0.0735494 (0.711)
Constant	49.55164*** (0.000)	44.73979*** (0.000)	59.06107*** (0.000)
R^2	0.6097	0.6044	0.6489
F-Stat	32.81*** (0.0000)	18.33*** (0.0000)	14.41*** (0.0000)

*, **, *** means significant at 1%, 5% and 10%, respectively
Source: Authors' Compilation

Table 4: GMM results

Variable	Aggregate	Pre-COVID	During COVID
logEV	0.1928788*** (0.000)	0.189086*** (0.000)	0.3914346*** (0.000)
logCF	−8.393885*** (0.000)	−7.853551*** (0.000)	−8.426252*** (0.000)
logREC	−0.5778984*** (0.000)	0.7261263*** (0.007)	−0.929405*** (0.000)
logGDPgr	−0.1777376*** (0.000)	−0.2361832 (0.304)	−0.2309486** (0.050)
logPOPgr	0.0876738** (0.037)	−0.9489448** (0.016)	0.7183131*** (0.001)
Constant	51.13446*** (0.000)	44.64862*** (0.000)	50.98054*** (0.000)
AR (1)	−8.51*** (0.000)	−5.37*** (0.000)	−3.03*** (0.000)
AR (2)	−1.54 (0.519)	0.47 (0.753)	0.92 (0.311)

*, **, *** means significant at 1%, 5% and 10%, respectively
Source: Authors' Compilation

emissions across the complete sample. This finding is consistent with the results of the POLS estimations provided in Table 3. Furthermore, the GMM models in Table 4 anticipated that a percentage increase in the number of electric vehicles equates to a 0.19% rise in total greenhouse gas emissions in the short term, assuming no other changes. This illustrates an inelastic relationship between these factors.

When comparing the pre-COVID and COVID periods, GMM computations indicated the same positive and statistically significant connection. Furthermore, an inelastic relationship between the number of electric vehicles and overall greenhouse gas emissions was established in both time frames. A percentage increase in the number of electric vehicles would result in 0.19% and 0.39% increases in greenhouse gas emissions prior to and during COVID, respectively.

The results in Table 4 reveal that the availability of clean fuels has a negative and statistically significant influence on overall greenhouse gas emissions across the complete sample. This finding agrees with the POLS estimations summarized in Table 3. Furthermore, according to the GMM predictions in Table 4, a one-point increase in access to clean cooking fuels and technology is predicted to result in an 8.39% reduction in total greenhouse gas emissions in the entire sample in the short term, providing all other factors remain constant. This exhibits a responsive relationship between these parameters. GMM computations verified the negative and statistically significant link in both the pre-COVID and during-COVID periods. Furthermore, an elastic link between the availability of clean fuels and overall greenhouse gas emissions was observed in both scenarios. A percentage increase in the availability of clean cooking fuels and technology would result in a 7.85% and 8.43% reduction in greenhouse gas emissions in the pre-COVID and COVID periods, respectively, providing all other parameters remained constant.

Table 4 revealed that the utilization of renewable energy had a significant and negative influence on total greenhouse gas emissions in the entire sample, which was consistent with the findings of the POLS estimates in Table 3. Furthermore, the GMM models in Table 4 demonstrated that increasing renewable energy consumption is related with a 0.58% reduction in total greenhouse gas emissions in the near run, assuming everything else remains constant. This illustrates an inelastic relationship between these factors. When comparing the pre-COVID and COVID periods, the GMM estimations revealed a positive and statistically significant association prior to COVID and a negative and statistically significant relationship during COVID. Specifically, a percentage increase in renewable energy consumption was projected to result in a 0.73% increase before COVID and a 0.93% decrease during COVID, while maintaining an inelastic relationship between renewable energy usage and overall greenhouse gas emissions in both timeframes.

The results presented in Table 4 showed that economic growth had a negative and statistically significant impact on total greenhouse gas emissions across the sample, which is consistent with the findings of Fuinhas et al. (2021) on the impact of battery electric vehicles on greenhouse gas emissions in 29 EU countries. However, this result contradicts the findings of Lapinskienė et al. (2017) in their analysis of energy consumption, economic development, and greenhouse gas emissions in European Union countries, as well as the POLS numbers in Table 3. Furthermore, according to the GMM estimates in Table 4, a rise in economic growth rates is predicted to result in a 0.18% reduction in total greenhouse gas emissions in the near run, provided all other parameters remain constant, demonstrating an inelastic relationship between these variables. When comparing the pre- and post-COVID periods, GMM calculations found a non-significant negative association between economic growth and greenhouse gas emissions prior to COVID, but a statistically significant negative relationship after COVID.

While the relationship between economic growth and greenhouse gas emissions was unclear prior to the COVID period, it was discovered that during the COVID period, a one percentage point increase in economic growth resulted in a 0.23% decrease in greenhouse gas emissions, assuming all other variables remained constant. This indicates an inelastic relationship between the variables during the COVID period. Furthermore, Table 4 indicated that population expansion had a positive and statistically significant influence on total greenhouse gas emissions across the entire sample, contradicting the POLS estimates in Table 3.

Furthermore, according to the GMM predictions in Table 4, a one-percentage-point rise in population growth rates is predicted to result in a 0.09% increase in total greenhouse gas emissions in the near run, assuming that all other parameters remain constant. This exhibits an almost entirely inelastic relationship between the variables. When comparing the pre- and post-COVID periods, the GMM estimations revealed a negative and statistically significant correlation before COVID, but a positive and statistically significant relationship after COVID. Specifically, a percentage rise in population growth rates was predicted to lead to a 0.95% reduction in greenhouse gas emissions before COVID, but a 0.72% increase after COVID, providing all other parameters maintained constant.

4.4. Discussion

The study's findings demonstrated that in the countries analyzed, both before and after the COVID-19 epidemic, the production of electric vehicles (EVs) entails energy-intensive manufacturing processes such as raw material extraction and processing, which can have major environmental repercussions. For example, if the manufacture of EV batteries relies substantially on fossil fuels or produces large emissions, any emissions reductions obtained over the vehicle's operational lifespan may be offset. Furthermore, the environmental impact of EVs is closely tied to the sources of electricity utilized for charging. If electricity is largely generated from nonrenewable sources such as fossil fuels, the usage of EVs may not result in significant benefits in terms of climate mitigation. However, expanding the usage of clean and renewable energy sources for electricity generation, as well as updating battery technology, may help to relieve these concerns.

Both analytical methodologies utilized in the study indicated that the availability of clean fuels had a negative influence on total greenhouse gas emissions across the sample. Improved availability to clean energy sources such as solar, wind, hydropower, geothermal, and biofuels resulted in lower greenhouse gas emissions in the countries surveyed, both before and after COVID-19. This is because clean fuels release little or no direct emissions of carbon dioxide (CO_2) and other greenhouse gases during operation, therefore minimizing the repercussions of climate change. Similarly, data from both techniques suggested that the use of renewable energy had a negative influence on total greenhouse gas emissions across the sample. In the countries investigated, both before and after COVID-19, increasing the usage of renewable energy greatly lowered the amount of carbon dioxide (CO_2) and other greenhouse gas emissions. This is owing to the fact that renewable energy sources do not require the combustion of fossil fuels and are obtained from naturally replenishing sources, making them a sustainable and long-term solution for satisfying energy demands without depleting finite resources or contributing to climate change.

The GMM computations found that economic expansion had a negative influence on greenhouse gas emissions throughout the sample and during the COVID-19 era. The findings are congruent with those of Begum et al. (2015), who observed that economic improvement in Malaysia was connected with a decline in CO_2 emissions. Countries that aggressively encourage investment and adopt legislation to support renewable energy usually enjoy economic growth that coincides with a transition away from fossil fuels and toward cleaner energy sources. Furthermore, economic growth may need modifications to a circular economy, which prioritizes resource conservation, reuse, and recycling. Although it is feasible to lower emissions while experiencing economic growth, historical patterns in other countries suggest that emissions usually rise alongside economic prosperity. It is vital for governments, corporations, and individuals to maintain promises to sustainability and climate-conscious policies in all sectors to ensure that economic growth is consistent with environmental protection and climate change mitigation initiatives.

According to GMM calculations, population expansion has a negative influence on total greenhouse gas emissions before COVID, but a positive impact during COVID in the nations under consideration. In the years preceding the COVID-19 pandemic, population expansion presented an opportunity to invest in renewable energy and energy efficiency. This investment was crucial to fulfill the increased demand for electricity in a sustainable manner. According to Satterthwaite (2009), population expansion does not automatically imply greater greenhouse gas emissions. Instead, the increase in consumption levels is considerable. Nonetheless, the COVID outbreak prompted a jump in population density, resulting in a large increase in energy demand for household activities. If fossil fuels account for the majority of this additional energy demand, greenhouse gas emissions will climb dramatically.

To summarize, population expansion does not fully change greenhouse gas emissions. To understand the complete influence of population expansion on emissions, researchers must analyze how it interacts with topics such as technology, law, and consumption habits. Implementing effective laws and regulations to promote sustainability, enhance renewable energy consumption, and develop low-carbon behaviors will assist to alleviate the environmental effects of population growth and bring us toward a more sustainable future.

4.5. Practical and Theoretical Applications

These findings have practical ramifications, including influencing policy decisions for climate change adaptation and mitigation. By revealing insight on stakeholder perspectives on climate change impacts and crucial measures, the study can help to build successful Efforts to minimize greenhouse gas emissions, protect vulnerable populations, and promote sustainable development. On a theoretical level, these findings help to better appreciate the delicate interplay of climate change, economic growth, and the utilization of renewable energy sources. The study's knowledge of how COVID-19 influences this interconnected framework helps to broader discussions on energy system resilience and stresses the significance of flexible and adaptive methods to sustainability planning. Furthermore, the study's investigation of stakeholder viewpoints can assist scholars comprehend the role of public opinion in determining environmental policy results.

4.5.1. Practical applications

(i) Policy formulation and adjustment: The findings can help governments and policymakers construct and adjust renewable energy initiatives. They can amend regulations to encourage economic growth while mitigating climate change, focusing on the specific issues and opportunities given by the COVID-19 outbreak;
(ii) Investment decisions: Investors and corporations can use the research to influence their investment decisions.

Understanding how clean energy adoption influences economic growth and climate change could help them find new answers in the coming post-pandemic period.

(iii) Employment creation: Research can help to shape employment creation plans. Understanding the link between clean energy and economic growth supports initiatives to establish new job possibilities, particularly in organizations focusing on clean energy production, research, and development. Resilience Planning: This research can assist governments and organizations in estimating the sensitivity of diverse sectors to pandemics and climate change. This insight is crucial for formulating measures to make economies more resistant to shocks;

(iv) International collaboration: The findings can impact global climate change agreements and alliances. Nations may combine their renewable energy efforts to boost economic growth and contribute to the attainment of global climate goals.

4.5.2. Theoretical applications

(i) Environmental economics: The study can contribute to the subject of environmental economics by giving insights into the intricate relationships between renewable energy adoption, economic growth, and climate change. This can help shape economic theories and concepts. Sustainable Development Ideas: The findings have implications for sustainable development principles. It can assist scholars comprehend how to balance economic growth with environmental protection, which is an important part of sustainable development; and

(ii) Systems thinking: The confluence of renewable energy, economic growth, and climate change in the framework of COVID-19 can be used to build and refine systems thinking models. These models can help us comprehend the complicated feedback loops and dynamics that govern these processes.

(iii) Public health and environment connection: The findings can help to direct future study into the link between public health and the environment. It enables scientists to explore how renewable energy adoption affects public health and, by extension, economic growth, while also treating the symptoms of sickness.

(iv) Interdisciplinary study: The challenge may lead to interdisciplinary research, bringing together specialists from economics, environmental science, public health, and other sectors. This interdisciplinary approach can lead to a more thorough knowledge of the limitations and potential at the nexus of renewable energy, the economy, and climate change.

5. CONCLUSION, IMPLICATIONS AND RECOMMENDATIONS

5.1. Conclusions

Climate change is a serious global concern, and countries around the world must take actions to reduce its consequences by reducing overall greenhouse gas emissions. Among the activities being addressed is the usage of electric vehicles, which has resulted in a considerable body of literature on the subject. However, this study dives deeper into the intricate interplay between renewable energy sources, economic growth, and climate change. The study explores and compares data from before and after the COVID-19 outbreak to find the link between clean fuel availability, renewable energy usage, per capita growth rates, and overall greenhouse gas emissions. The data demonstrates a negative correlation between these renewable energy proxies and emissions.

This study contributes to the policy discussion aimed at reaching the Sustainable Development Goals (SDGs) by addressing endogeneity issues with both the pooled ordinary least squares (POLS) and the one-step system generalized method of moments (GMM) estimators. It focuses on how clean technologies, such as electric vehicles, clean cooking and lighting fuels, renewable energy, and renewable electricity output, can help achieve the SDGs of good health and well-being, clean water and sanitation, industry, innovation, and infrastructure, climate action, sustainable cities and communities, life below water, and life on land.

Adopting clean energy sources appears to be a critical step toward lowering greenhouse gas emissions, mitigating climate change, and assuring a sustainable future. Embracing these technologies helps us transition to a low-carbon, resilient, and ecologically responsible energy system, opening the route for a cleaner, greener, and wealthier future. However, in order to make this promise a reality, governments must give broad legislative backing, significant infrastructural investments, widespread public awareness and education, and major international participation. Renewable energy sources will only be completely implemented and exploited to their full potential in terms of reducing overall greenhouse gas emissions and mitigating climate change if efforts are coordinated.

5.2. Limitations and Recommendations for Further studies

One weakness of this study is its limited sample size, which may not reflect all stakeholders. Future research should enhance the sample size and include a larger spectrum of stakeholders, such as politicians and industry leaders. Another difficulty is the dependence on subjective rather than objective assessments of climate change impacts and solutions. Future study may include objective data to validate and supplement stakeholders' perspectives.

Furthermore, the study did not examine the potential trade-offs and conflicts related with various adaptation and mitigation techniques. Subsequent research could delve into these trade-offs to determine the optimal solutions that balance economic, social, and environmental issues. Furthermore, the study did not evaluate the role of international cooperation in climate change mitigation initiatives. Future study could focus on the potential and limitations of global climate governance, as well as how these affect policy decisions at the country level.

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