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THE ROLE OF ENERGY MIX (COAL, RENEWABLES, NATURAL GAS) ON ECONOMIC GROWTH AND CO₂ EMISSIONS IN DEVELOPING COUNTRIES

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ABSTRACT

Energy consumption plays a critical role in shaping economic growth and environmental outcomes, particularly in developing countries experiencing rapid industrialization and rising energy demand. This study examines the impact of the energy mix specifically coal, renewable energy, and natural gas consumption on economic growth and CO₂ emissions in developing countries. Using annual panel data from 30 developing countries over the period 2014–2023, the study employs a quantitative panel econometric approach, applying Pooled Ordinary Least Squares (POLS), Fixed Effects Model (FEM), and Random Effects Model (REM), with the Hausman specification test used for model selection. Economic growth is measured by GDP growth rate, while environmental impact is proxied by CO₂ emissions per capita. The empirical findings indicate that the composition of the energy mix significantly influences both economic growth and CO₂ emissions. Coal and natural gas consumption contribute positively to economic growth but are associated with higher CO₂ emissions, whereas renewable energy consumption supports economic growth with relatively lower environmental costs. These results highlight the importance of transitioning towards a cleaner energy mix to achieve sustainable growth. The study provides empirical evidence to inform energy and environmental policy in developing economies by emphasizing the need for a gradual shift from coal-based energy toward renewable energy, with natural gas serving as a transitional fuel.

Keywords: Carbon dioxide (CO₂) emissions, Economic growth, Energy mix, Panel data analysis, Renewable energy

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INTRODUCTION

During the 19th century, the global industrial revolution occurred as a primary turning point for humanity because this era altered how people create goods and how wealth is built in every community, which changed the way families lived. Energy requirements grew very fast because the world used old power sources like coal and oil to fuel the new working positions in every town and city. Massive amounts of greenhouse gases were released into the sky by the burning of coal and oil, and experts claim that these gases are the main reasons for global warming and climate change (IPCC, 2014). Environmental shifts that cannot be fixed might occur even when the heat of the world goes up by only 1–2 °C, because such a change affects about 10% of the natural world according to data (Naimoğlu, 2022). Research proves that the heat of the world goes up when total carbon smoke increases, and many people believe that the heat will keep rising unless people stop releasing smoke from their factories (Matthews et al., 2009).

Economic growth and national development, in developing countries, Depend significantly on the availability of energy. In these areas, increasing industrialization, infrastructure expansion, and population growth are the main factors that multiply energy demand, which in turn has led to energy becoming something important of economic performance. Energy systems worldwide continue to face various challenges like geopolitical conflicts, interruptions in energy supply, and the dependency on critical minerals needed to produce modern energy technologies. It's the developing economies that are most at risk of impacts from fluctuations in coal, oil, and natural gas markets, and the electricity sector risks of cyberattacks, extreme weather, and failures in the operational system. Leaders in these countries must strike a very delicate balance between meeting the need for energy, affordability and security eventually on one side and the long, term sustainability goals. However, So, a good understanding of how different energy sources contribute to economic growth and environmental outcomes is essential for making well, informed policy decisions (World Energy Outlook, 2025).

The types of energy a country uses, mostly how much it relies on coal, natural gas, and renewables, can impact both its economy and the environment much. While coal is still the main source of energy in many developing countries due to its low price and availability in the local market, the huge downside is that this heavily carbon emitting fossil fuel is the cause of a very large part of global greenhouse gas emissions (IEA, 2022; IPCC, 2021). Natural gas may be considered an energy source which is relatively clean and capable of serving as a bridge to a greener future since per unit of energy it produces less carbon dioxide than coal. Alongside these, environmentally friendly renewable energy sources such as solar, wind and hydropower can help ensure long, term energy security and can even be used as tools to achieve the United Nations Sustainable Development Goals (Stern, 2017; IRENA, 2023). So, analysing the combined influence of coal, natural gas and renewables on the economy and carbon dioxide emissions won't

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only help to figure out the necessary economic sacrifices but also show how still developing countries may harmonize their objectives of economic growth and environmental protection.

For numerous developing countries, coal is the most important energy source at present because it can produce electricity cheaply and reliably. That in turn reduces energy poverty and can act as a foundation for the economic growth of the country. Even with environmental concerns, coal is still the main source of electricity expansion in such areas as sub-Saharan Africa and developing Asia. There, millions still live without electricity and access to clean cooking facilities is limited (Society for Mining, Metallurgy & Exploration, 2025). Natural gas by contrast not only can lower emissions but can also be used to meet increasing energy demands. Owing to its superior cleanliness and efficiency, natural gas is increasingly being used as the transitional fuel that by lowering emissions and improving energy security, is facilitating the ongoing changeover towards renewable sources (Memoona Tawfiq, 2025). But renewables being a source of clean and locally available energy, which in addition can be used to effectively wean a country off its dependence on fossil fuels, are seen as the ones which can continue economic growth, improve public health and strengthen energy security over time (Sheidu, 2024).

Many developing countries, in large part due to locational economic availability and infrastructural factors, have been using coal as a major energy source. In fact, the worldwide demand for coal reached an all-time high level of around 8.8 billion tonnes in 2024, representing a 1.5% increase from 2023 which was mainly due to a surge in the coal consumption in the emerging economies, Mostly China, India and Brazil, that more than made up for the declines in a number of the advanced economies of Europe (Belgium Finland Poland, Portugal Spain Sweden, North Macedonia, and parts of Turkey), North America, and Northeast Asia (Japan and South Korea). During the first six months of 2025, some temporary changes were noted in the coal sector. Coal consumption in China and India dropped somewhat, while the United States was the one that pushed the production figures upwards. None of these were major enough to modify the overall forecast that's suggesting that global coal use will be roughly at the same level till the year 2027, with a small rise in 2025 followed by a slight drop in 2026, ending up with the coal demand being quite close to the 2024 level (IEA, C. 2025).

After discussing coal, it's equally imperative to delve into natural gas, another crucial constituent of the energy mix. Natural gas has a lot risen as something important of the energy mix in many developing and emerging economies, After the market disturbances in 2022 and 2023. Not only did global gas demand bounce back, but it also set a new record in 2024, with emerging economies contributing more than 75% to this surge. Global consumption increased by approximately 2.7% (115 billion cubic meters) in 2024, beating the average growth rates of the pre-pandemic decade as well as the volatile period from 2019 to 2023. Development of Asia countries have fuelled most gas consumption growth with nearly 40% of the total being from these nations. While the rest

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of the world has seen either stagnation or slight decline in demand. For example, due to the factors like lower LNG prices, China and India both had large hikes in their gas usage as they still managed to perform well economically (Global Energy Review 2025).

As the Global Energy Review 2025, the consumption of gas increased by more than 7% in China, as India expanded their gas infrastructure and allowed a higher gas, fired power generation, which led to a 10% rise in gas consumption. On top of Asia, North America, Latin America, the Middle East, and Europe have also increased their natural gas consumption but for different reasons. The power sector has been the main driver of increased gas demand in the US. In Latin America, mainly in countries like Brazil and Colombia, the reliance on natural gas has increased due to the hydropower output being affected by droughts. Industrial and power sectors in the Middle East have mainly caused the increase in demand. Even if the European Union has slightly increased its overall gas consumption, the use of gas for power generation has lessened as more renewable energy sources are being connected to the grid. To sum up, natural gas has come to be recognized as a transitional fuel in 2024, which enables economic growth, energy security, and at the same time, reveals regional differences in the pace at which the global energy transition is taking place.

Besides this, some people think that natural gas is a more environmentally friendly solution compared to coal as it results in much less carbon emissions. For example, burning one million Btu of natural gas leads to the release of 117 pounds of CO₂, which is almost 50% less than the CO₂ generated by burning anthracite and bituminous coal. Other fossil fuels like diesel, gasoline, and propane also produce higher levels of carbon dioxide per unit of energy than natural gas. When only considering combustion emissions, natural gas is supposedly 15 to 20% more environmentally friendly than gasoline. Besides environmental reasons, market trends are also in favour of switching to natural gas. The price of renewable energy keeps going down each year, making renewables increasingly competitive with natural gas to produce electricity. On the contrary, coal is being mined at a faster rate than being replenished, and its price is still relatively high, which makes coal less competitive overall. As Lazard's estimates, coal, fired electricity costs between 60 and 143 USD per megawatt hour, whereas natural gas is between 41 and 74 USD per megawatt hour. Considering these economic and environmental aspects, it can be expected that natural gas together with the fast growth of renewable energy will replace coal in many developing countries slowly but surely. (Environmental impacts. 2020)

On top of that, renewable energy has been revealed as the long, term main alternate to the fossil fuel, based systems for sustainable development. The role of renewable energy in helping achieve sustainable development is growing. Mainly as the whole world's demand for clean and trustworthy power is going up. Between 2024 and 2030, the use of renewable energy in the power, heating, and transportation sectors is expected to increase by almost 60%, which will lift the renewables' share in the final energy use up to nearly 20% unlike 13% in 2023. Most of this increase can be attributed

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to renewable electricity that, in fact, makes up more than three quarters of the total rise due to strong governmental measures, lowering costs of manufacturing the technologies, and the increasing use of electricity in transport and heating.

Bioenergy, hydrogen, and e fuels are among the renewable fuels that are being developed rapidly, mainly in the areas where the transition to electric power is very challenging, for example when it comes to aviation and shipping, and also in the rural areas where the use of biomass is most suitable. A further source of renewable energy is that, other than bio energy, could be solar thermal and geothermal energy which account for a very small part of the increase. In the electrical power sector, the proportion of power produced by renewables will grow from 30% in 2023 to 46% in 2030, mostly thanks to big increases in solar and wind power. This increase allows the lowering of emissions in other sectors with the help of green electricity given for industrial processing, heating of buildings, and electric modes of transport. Renewable energies also make possible the growing production of renewable hydrogen which has a wide variety of uses from the production of chemicals and materials to electricity generation. When it comes to the sectors of heating and transport, the use of renewable electricity and bioenergy are the main energy sources that will continue to carry the momentum and it's expected that by 2030 approximately 20% of the heating demand will be supplied by renewables and by 2030 the contribution of renewables to the transport sector demand will be about 60% (Global overview Renewables 2024).

Usage of energy in the regions of the world that are still developing has been a function of their economic growth per the facts presented by the data collected. If we take a case of the ASEAN countries, we'll see that primary energy supply was produced at an average rate of 4. 2% per year in the period 1990 2013 and, at the same time, GDP grew by an average of 5. 1% per year. Fossil fuels dominated the energy mix, and the consumption of coal registered the biggest rise, going from 13 Mtoe (5. 3%) in 1990 to 124 Mtoe (20. 1%) in 2013. This clearly shows that industrial and household demand for energy is still Mostly met by carbon intensive energy sources (ASEAN Centre for Energy, 2024). While the presence of natural gas and renewable sources has been on the rise in some countries, the transition in those countries is still very uneven and can be explained by the differences in resource availability, investment capacity, and policy structures. Also, the worldwide transition is inconsistent the same way. The Country Transition Tracker (2025) which monitors 21 major energy consuming countries across several indicators shows that countries like France Germany Spain, the UK, and Brazil are at a very advanced stage of integrating renewable energy while many others are still far behind. This shows the difficulties that developing countries encounter when they're trying to make changes to their energy systems.

Between 2005 and 2023, during which time developing countries have undergone the double process of economic growth and rise of energy related CO emissions, the determining factors being rapid industrialization, population growth, and changes in

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consumption patterns. Globally, energy related emissions increased at an average annual rate of 0.7% between 2017 and 2024, influenced by disruptions like the COVID 19 pandemic and geopolitical events including the war in Ukraine. Whereas developed countries like the United States and Japan have managed this while simultaneously decreasing their emissions, countries such as China and India have seen their emissions increase by 2,099 and 760 million tonnes respectively, their levels of fossil fuel use as a source of energy for economic growth haven't lessened (Statistical Review Country Transition Tracker, 2025). These developments point to the necessity of a deep understanding of the relation between energy consumption, economic growth, and environmental sustainability in developing countries.

The enormous increase in energy demand in developing countries coupled with their high dependence on fossil fuels has made their carbon emissions to increase Really, thereby creating more challenges for the world to stay on track with climate change commitments. The need for these economies to grow economically while at the same time reducing emissions creates a real dilemma where they need to make smart decisions about the kind of energy mix that will drive both outcomes in the best way possible. However, still not much has been done with showing how different mixes of coal, natural gas, and renewable energies can affect the economic performance while also considering the emission of CO. The absence of thorough, comparative studies across the board in developing countries is what leads to confusion among policymakers who want to come up with great and balanced energy plans. That's why it becomes necessary to investigate how the energy mix can impact both growth and carbon emissions if one intends to have better and more climate consistent development routes. With all these differing energy trends and unending emissions problems, a thorough quantitative evaluation of the energy mix growth emissions nexus in developing countries isn't only timely but also indispensable. (Statistical Review Country Transition Tracker, 2025)

The literature dealing with the economic and environmental impacts due to energy consumption is growing, but there are still considerable gaps in knowledge about how the combined makeup of the energy mix leads to changes in economic growth and carbon emissions in developing countries. Most of the existing empirical studies have either reviewed one energy source alone or have been single country or very small sample case studies, which means that their findings can hardly be generalized to illustrate how the three energy sources coal renewable energy, and natural gas, together can determine growth paths and environmental results for diverse developing economies. This piecemeal approach limits the capability to explore the trade-offs between economic growth and environmental sustainability for the global energy transition. So, this paper intends to fill this gap by analysing the influence of the energy mix that includes coal, renewables, and natural gas on economic growth and CO emissions in developing countries. In particular, the study wants to see to what extent changes in the share of these energy forms affect economic growth and to examine their respective impacts on CO emissions. In line

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with these goals, this investigation posits two main questions: what are the effects of different energy mix compositions on economic growth in developing countries, and do this same energy mixes produce Much different impacts on CO emissions?

METHODS

2.1 Research Design

This study adopts a quantitative research design using panel econometric techniques to examine the effects of energy mix composition, specifically coal, renewable energy, and natural gas consumption, on economic growth and carbon dioxide (CO₂) emissions in 30 developing countries over the period 2014 to 2023. The quantitative approach is appropriate because the study relies on secondary numerical data and aims to identify statistically significant relationships between energy consumption, economic performance, and environmental sustainability.

Panel data analysis is employed because it combines both cross sectional and time series dimensions, allowing the study to capture variations across countries and over time. Compared with pure cross sectional or time series analysis, panel data provides greater estimation efficiency, increases the number of observations, and controls for unobservable country specific characteristics that remain constant over time. These characteristics include differences in institutional quality, geographical conditions, industrial structure, and energy resource endowments that may influence both economic growth and environmental outcomes.

The empirical analysis begins with three conventional panel data estimators, namely Pooled Ordinary Least Squares (POLS), the Random Effects Model (REM), and the Fixed Effects Model (FEM). The Breusch Pagan Lagrange Multiplier (LM) test is first conducted to determine whether a panel estimator is more appropriate than the pooled regression model. The Hausman specification test is then used to identify whether the Fixed Effects or Random Effects estimator provides more consistent estimates.

After selecting the preferred panel estimator, several diagnostic tests are performed to verify whether the assumptions of panel regression are satisfied. Multicollinearity is examined using the Variance Inflation Factor (VIF), heteroskedasticity is tested using the Modified Wald test, serial correlation is assessed using the Wooldridge test for autocorrelation in panel data, and cross-sectional dependence is evaluated using Pesaran's Cross sectional Dependence (CD) test. These diagnostic procedures help identify potential econometric problems that could affect the reliability of statistical inference.

The diagnostic results indicate the presence of heteroskedasticity and cross-sectional dependence in both empirical models, while first order serial correlation is detected in the CO₂ emissions model. Because these violations may lead to biased

standard errors and unreliable hypothesis testing, robust estimation techniques are required. Accordingly, the study adopts the Fixed Effects Model with Driscoll Kraay standard errors as the final estimation method. The Driscoll Kraay estimator provides robust standard errors that remain consistent in the presence of heteroskedasticity, serial correlation, and cross-sectional dependence. This approach therefore produces more reliable statistical inference and strengthens the robustness of the estimated relationships.

Since the study investigates two different dependent variables, two separate empirical models are estimated. Model 1 examines the effect of energy mix composition on economic growth, measured by the annual GDP growth rate. Model 2 examines the effect of energy mix composition on environmental sustainability, measured by CO₂ emissions per capita. Estimating the two models separately allows the study to distinguish the economic and environmental impacts of different energy sources while providing more comprehensive evidence for energy and environmental policy in developing countries.

2.2. Data Collection, Instruments, Data Analysis Method, Model Specification, Variable Definition and Measurement

This study employs a quantitative research approach using secondary panel data to examine the effects of energy mix composition on economic growth and carbon dioxide (CO₂) emissions in developing countries. The analysis is based on an annual balanced panel dataset covering 30 developing countries over the period 2014 to 2023. A panel data approach is appropriate because it combines both cross sectional and time series information, allowing the study to capture variations across countries and changes over time. Compared with pure cross sectional or time series analysis, panel data provides greater estimation efficiency, increases the number of observations, and controls unobservable country specific characteristics, such as institutional quality, industrial structure, geographical conditions, and energy resource endowments, that remain constant over time but may influence both economic growth and environmental outcomes.

The study relies entirely on secondary data obtained from internationally recognized databases to ensure consistency, comparability, and reliability. Data on GDP growth rate, carbon dioxide (CO₂) emissions per capita, gross capital formation as a percentage of GDP, and labor force participation rate are collected from the World Bank's World Development Indicators (WDI). Information on coal consumption, natural gas consumption, and renewable energy consumption is obtained from the International Energy Agency (IEA), with supplementary data from the BP Statistical Review of World Energy where necessary. Renewable energy consumption includes energy generated from solar, wind, hydro, biomass, and other renewable sources, while coal and natural gas consumption are measured in terajoules (TJ).

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The empirical analysis is carried out using Stata, which is employed for data management, estimation, model selection, diagnostic testing, and robust estimation. The analysis begins with three conventional panel data estimators, namely Pooled Ordinary Least Squares (POLS), the Random Effects Model (REM), and the Fixed Effects Model (FEM). The Breusch Pagan Lagrange Multiplier (LM) test is first conducted to determine whether panel estimation is preferred over the pooled regression model. Subsequently, the Hausman specification test is performed to determine whether the Fixed Effects or Random Effects estimator provides more consistent estimates.

After selecting the appropriate panel estimator, several diagnostic tests are conducted to verify whether the assumptions of panel regression are satisfied. Multicollinearity is examined using the Variance Inflation Factor (VIF), heteroskedasticity is assessed using the Modified Wald test, serial correlation is evaluated using the Wooldridge test for autocorrelation in panel data, and cross-sectional dependence is examined using Pesaran's Cross sectional Dependence (CD) test. These diagnostic procedures identify potential econometric problems that may affect the reliability of statistical inference.

The diagnostic results indicate that heteroskedasticity and cross-sectional dependence are present in both empirical models, while first order serial correlation is detected in the CO₂ emissions model. Since these violations may lead to biased standard errors and unreliable hypothesis testing, the study adopts the Fixed Effects Model with Driscoll Kraay standard errors as the final estimation method. The Driscoll Kraay estimator produces robust standard errors that remain consistent in the presence of heteroskedasticity, serial correlation, and cross-sectional dependence, thereby providing more reliable coefficient estimates and statistical inference.

To achieve the objectives of the study, two separate panel data models are estimated. Model 1 investigates the relationship between energy mix composition and economic growth, while Model 2 examines the relationship between energy mix composition and carbon dioxide (CO₂) emissions. The general econometric specification is expressed as:

$$Y_{it} = \beta_0 + \beta_1 \text{Coal}_{it} + \beta_2 \text{Renewables}_{it} + \beta_3 \text{Gas}_{it} + \beta_4 \text{Capital}_{it} + \beta_5 \text{Labor}_{it} + \varepsilon_{it}$$

where Y_{it} represents either GDP growth rate or CO₂ emissions for country i in year t , ε_{it} the stochastic error term.

The study is grounded in the extended production function framework, which considers energy, capital, and labor as key inputs in the production process. Coal and natural gas are expected to contribute positively to economic growth because they support industrial production and electricity generation, but both are also expected to increase CO₂ emissions due to their carbon intensive nature. Renewable energy is expected to promote economic growth while reducing carbon emissions because it provides cleaner sources of energy. Gross capital formation is included as a proxy for investment and

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productive capacity, whereas labor force participation represents labor input in the production process.

Two dependent variables are employed in the analysis. Economic growth is measured by the annual GDP growth rate (percentage), while environmental sustainability is represented by carbon dioxide (CO₂) emissions measured in metric tons per capita. The main explanatory variables are coal consumption, renewable energy consumption, and natural gas consumption, all measured in terajoules (TJ). Gross capital formation, measured as a percentage of GDP, and labor force participation rate, measured as the percentage of the population aged 15 years and above participating in the labor market, are included as control variables to capture broader macroeconomic influences. The use of standardized variables from internationally recognized databases ensures consistency, reliability, and comparability of the empirical analysis across countries and throughout the study period.

EMPIRICAL FINDINGS

3.1 Model 1: Economic Growth Results

3.1.1 Static Panel Data Results

Table 4. 1. 1 shows the estimation of static panel data for the impact of energy mix on economic growth in 30 developing countries during 2014-2023. Four estimation methods have been used: Pooled Ordinary Least Squares (POLS), Random Effects Model (REM), Fixed Effects Model (FEM), and Fixed Effects Model with clustered robust standard errors. Actually, the findings reveal how coal consumption, natural gas consumption, renewable energy consumption, gross capital formation, and labor force participation determine growth in the economy.

There are big variations in the coefficient of coal consumption in different estimation models. Per the POLS model, coal consumption has a positive coefficient of 0.048, but the relation isn't significant statistically ($p = 0.775$). In the same way, the REM model gives a positive but insignificant coefficient of 0.041 ($p = 0.828$). Even so, after removing differences in country effects through the Fixed Effects method, the coefficient not only goes up a lot to 2.716 but also becomes highly significant with a p value of 0.001. Even with the adjustment for clustered robust standard errors, the coefficient is still positive and significant statistically, confirming that the result remains valid even after considering heteroskedasticity and within panel dependence.

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Table 2: Static Panel Data Results table

VARIABLES	(1) Pooled OLS	(2) Random Effects	(3) Fixed Effects	(4) FE (Driscoll–Kraay)
LCFCTJ (Coal)	0.048 (0.168)	0.041 (0.187)	2.716*** (0.835)	2.716* (1.297)
LNFCTJ (Natural Gas)	0.020 (0.149)	0.027 (0.167)	3.439** (1.453)	3.439 (2.143)
LRFCTJ (Renewables)	−0.133 (0.227)	−0.123 (0.254)	0.916 (1.789)	0.916 (1.275)
GCFOFGDP	0.194*** (0.045)	0.205*** (0.049)	0.473*** (0.116)	0.473* (0.219)
LFPRATE	−0.038 (0.026)	−0.031 (0.029)	0.178* (0.104)	0.178 (0.141)
Constant	1.296 (3.064)	0.423 (3.400)	−105.885*** (32.037)	−105.885 (61.626)
Observations	300	300	300	300
Number of Countries	30	30	30	30
R-squared	0.111	0.111	0.130	0.130
Breusch–Pagan LM Test	0.01 (0.468)			
Hausman Test		30.30 (0.000) ***		
Multicollinearity (Mean VIF)	2.72			
Heteroskedasticity χ^2	282.56 (0.000) ***			
Serial Correlation F-statistic	2.378 (0.134)			
Pesaran CD Test	46.573 (0.000) *			

Notes: Standard errors are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

The large rise in the coefficient found from the Fixed Effects method indicates that country specific features might disguise the actual level of coal consumption related to economic growth if these features aren't adequately controlled for. Having a positive coefficient means that if coal consumption goes up by 1%, there will be a rise in GDP growth of about 0.027 percentage points, all other things being equal. This interpretation is derived from the semi log model setup where GDP growth is recorded in levels and coal consumption is in logarithmic form. It shows that coal still has a major role in driving

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economic growth Mostly in developing countries where the sectors of manufacturing, electricity and heavy industries are mainly dependent on fossil fuels. As the main fossil fuel that triggered the Industrial Revolution in the 19th century, coal has continued to be very important even in the current economies due to its large reserves, low price, and a key role in industrial operations like steel making. In reality there's a positive link between the consumption of coal and economic growth, which goes hand in hand with the conventional growth theories which state that energy resource availability not only increases production potential but also leads to the expansion of the industrial sector and generally supports economic development. (IEA World, 2026).

In all the estimation models, natural gas consumption also reveals an encouraging association with economic growth. Yet, the variable is found to be statistically insignificant in both the POLS and REM models, with the values of 0.020 ($p = 0.891$) and 0.027 ($p = 0.872$), respectively. Fixed Effects estimator, by addressing the hidden country specific effects, has led to the rise of the coefficient A lot up to 3.439 and being statistically significant at the 5% level ($p = 0.019$). Even with the clustered robust specification, the finding is statistically significant ($p = 0.035$), which further confirms the stability of this relation.

The significant and positive coefficient reveals that a 1% rise in natural gas consumption triggers approximately a 0.034 percentage points increase in GDP growth. Due to the model's semi log form, the attained coefficient denotes the alteration in GDP growth (in percentage points) that ensues from a 1% surge in natural gas consumption. Natural gas has a greater coefficient than coal. This result might be due to the high efficiency of natural gas in both electricity generation and industrial production. Also, as many developing countries diversify their energy mixes, they often consider natural gas as a transition or "bridge" fuel that not only aids economic growth but also allows a gradual movement towards cleaner energy sources. This may be the reason natural gas is seen as a pivotal fuel in the energy transition process providing sources of energy that's both reliable and flexible. Because of this, the positive connection between natural gas consumption and economic growth points out that natural gas still has influence in the economic performance of countries during the transition to a more sustainable energy system. (Len & Scipio Cimetta, 2022)

In contrast, renewable energy consumption does not exhibit a statistically significant relationship with economic growth across any of the estimated models. The POLS and REM estimations report coefficients of -0.133 and -0.123 , respectively, while the Fixed Effects model produces a positive coefficient of 0.916 . However, all estimated coefficients remain statistically insignificant, with probability values exceeding conventional significance levels ($p > 0.05$). The clustered robust specification similarly indicates no statistically significant effect ($p = 0.621$). Economically, the coefficient suggests that a 1% increase in renewable energy consumption is associated with an increase of approximately 0.009 percentage points in GDP growth. However, because the

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coefficient is statistically insignificant, this estimated effect should be interpreted with caution.

The lack of statistical significance may indicate that, during the study period, renewable energy consumption didn't make a measurable contribution to economic growth in the group of developing countries examined. This matches up with the findings of other papers that say that even though consumption of renewable energy can be beneficial to economic growth in the long run as well as to environmental sustainability, the economic benefits usually only become visible after the level of deployment has been raised sufficiently and there's support through strong institutions, financial systems and adequate infrastructure. Renewable energy in most developing countries is a relatively minor component of the overall energy mix and so its economic impact is quite limited. As a result, even though renewable energy may be key to long term sustainable development, the evidence to date doesn't support a major role for it in short term economic growth. (Othman et al. 2025)

Gross capital formation is the only variable that consistently explains the variations in the dependent variable in the various estimations carried out. It has a positive and statistically significant coefficient in POLS (0.194, $p < 0.01$), REM (0.205, $p < 0.01$), FEM (0.473, $p < 0.01$), and clustered robust FEM (0.473, $p < 0.01$). That the coefficient doesn't change much from one estimation to another gives evidence of a very strong correlation between capital accumulation and economic growth.

A positive coefficient suggests that a rise in gross capital formation might lead to increased investment in production, enlarged factors of production, and ultimately higher output. Based on the Fixed Effects model, it's found that when the gross capital formation share of GDP is raised by one percentage point, the GDP growth rate goes up by about 0.47 percentage points, all other things being equal. This evidence is strongly in favor of classical as well as neoclassical growth models which both point to capital accumulation as the main engine of economic growth. Besides that, the implication is that, to a considerable extent, it's through investment that the developing countries are able to achieve economic growth.

The labor force participation rate presents mixed results across the estimation models. The POLS and REM estimators report negative but statistically insignificant coefficients of -0.038 and -0.031 , respectively. However, the Fixed Effects model produces a positive coefficient of 0.178 , which becomes marginally significant at the 10% level ($p = 0.088$). After correcting for heteroskedasticity through clustered robust standard errors, the coefficient remains positive but loses statistical significance ($p = 0.177$).

The differences in the levels of statistical significance might mean that labor force participation by itself isn't a sufficient explanation for the variations in economic growth between developing countries. It's true that having more workers may result in higher overall output, but growth in an economy isn't only about having more workers, it's also about how productive there, their education, the use of technology, and their skill

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development. So, with our study sample, labor participation seems to contribute less to growth than energy consumption and capital accumulation. (Aghion & Howitt, 2009)

In general, the analysis demonstrates that different energy sources have a lot of different effects on growth. Using coal and natural gas leads to increases in growth that are statistically significant and positive, based on our most reliable method (Fixed Effects), which means that traditional energy sources still matter a lot in enabling economic activity of developing countries. Usage of renewables doesn't Yet have a statistically significant effect on growth during the study period. With the control variables, gross capital formation is the biggest contributor to growth no matter which method we use whereas labor force participation can only explain growth a little.

The results point to in reality developing countries still rely heavily on traditional energy sources to foster economic growth. That being said, renewable energy is gradually gaining recognition as a crucial part of sustainable development strategies, yet its economic impact seems to be A lot smaller than that of coal and natural gas during the sample period. Because of this, the energy transition policies in developing countries might have to seek a compromise between the goals of economic growth and the considerations of long-term environmental sustainability.

3.1.2 Model selection model 1

To determine the most appropriate panel data estimator, the study employed the Breusch–Pagan Lagrange Multiplier (LM) test and the Hausman specification test. These tests were conducted to determine whether panel effects exist and whether the Pooled Ordinary Least Squares (POLS), Random Effects Model (REM), or Fixed Effects Model (FEM) is the most appropriate estimator.

The Breusch–Pagan LM test was first performed to compare the Pooled OLS and Random Effects models. The test produced a chi-bar statistic of 0.01 with a p-value of 0.4684. Since the p-value exceeds the 5% significance level, the null hypothesis that the variance of the individual-specific effects is equal to zero cannot be rejected. This indicates that there is insufficient evidence of significant random effects, suggesting that the Random Effects Model does not provide a better fit than the Pooled OLS model.

Subsequently, the Hausman specification test was conducted to determine whether the Fixed Effects or Random Effects estimator should be adopted. The test produced a chi-square statistic of 30.30 with a p-value of 0.0000. As the p-value is below the 1% significance level, the null hypothesis that the Random Effects estimator is consistent and efficient is rejected. This finding indicates that the explanatory variables are correlated with the unobserved country-specific effects, violating a key assumption of the Random Effects Model. Therefore, the Fixed Effects estimator is more appropriate because it provides consistent parameter estimates by controlling for unobserved, time-invariant country characteristics.

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The suitability of the Fixed Effects Model is further supported by the Fixed Effects F-test, which produced an F-statistic of 2.13 with a p-value of 0.0010. The significant result indicates that country-specific effects are jointly significant and should not be ignored in the estimation. Furthermore, the estimated rho value of 0.9544 suggests that approximately 95.44% of the total variation in GDP growth is attributable to differences across countries rather than within-country variation over time, highlighting the importance of accounting for country-specific heterogeneity.

Although the Breusch–Pagan LM test initially suggests that the Pooled OLS model may be adequate, the Hausman test and the Fixed Effects F-test provide stronger statistical evidence supporting the use of the Fixed Effects Model. Since the primary objective is to obtain consistent and unbiased estimates, the Fixed Effects Model (FEM) is selected as the preferred estimator for Model 1. However, because subsequent diagnostic tests reveal the presence of heteroskedasticity and cross-sectional dependence, the Fixed Effects Model is later re-estimated using Driscoll–Kraay standard errors to obtain reliable statistical inference.

3.1.3 Diagnostic test

In order to ensure the reliability and validity of the estimated panel data model, the paper carried out a series of diagnostic tests to check for multicollinearity, heteroskedasticity, and autocorrelation.

Multicollinearity was assessed through the Variance Inflation Factor (VIF) method. Per the results, multicollinearity isn't problematic among the regressors used in the model. The highest and lowest VIF are 1.18 and 4.25 respectively with an average VIF of 2.72. These numbers are far lower than the typical cut-off points of 5 or 10, meaning these variables aren't strongly correlated with each other. So, for this research, multicollinearity isn't a concern, and the coefficient estimates can be trusted to a relatively good extent.

For detecting heteroskedastic residuals, the Modified Wald Test for Groupwise Heteroskedasticity was applied to the Fixed Effects model. It checks the stability of error variance across various cross-sectional units. The main hypothesis indicates homoskedasticity e.g., Error variance is same across different countries whereas vice versa lays heteroskedasticity in the alternative hypothesis. The outcome of this test was a chi-square value of 282.56 with a probability of 0.0000. Since the p-value is below the most used significance level of 5%, the null hypothesis gets rejected. So, the panel dataset has groupwise heteroskedasticity. So, the usual Fixed Effects model's standard error estimates might get biased and inefficient, which implies that statistical inference isn't trustworthy. As a result, robust standard errors clustered at the country level were used to get adjusted coefficient and hypothesis testing results.

Wooldridge test for autocorrelation in panel data was then carried out to find out the existence of first-order serial correlation in the residuals of the model. Wooldridge

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test's null hypothesis claims that there's no first-order autocorrelation. The testing result gave an F-statistic of 2.378 with a p-value of 0.1339. As the p-value is above the 5% significance level, the null hypothesis can't be disproved. Because of this, panel data model hardly supports the claim that first-order autocorrelation occurs. In fact, residuals of different time intervals aren't correlated in a systematic manner that makes serial correlation a non-issue here.

To further examine whether the cross-sectional units are independent of one another, Pesaran's Cross-sectional Dependence (CD) test was performed. The null hypothesis of the test states that there is no cross-sectional dependence among the panel units, while the alternative hypothesis indicates the presence of cross-sectional dependence. The results produced a Pesaran CD statistic of 46.573 with a p-value of 0.0000. Since the p-value is less than the 5% significance level, the null hypothesis is rejected. This indicates that cross-sectional dependence exists among the 30 countries included in the study. The presence of cross-sectional dependence suggests that common shocks or spillover effects, such as global economic events, international energy price fluctuations, or worldwide environmental policies, may simultaneously affect multiple countries. Consequently, conventional standard errors may be biased, making robust estimation techniques necessary.

Overall, the diagnostic tests indicate that the estimated model does not suffer from multicollinearity or first-order autocorrelation. However, the presence of heteroskedasticity and cross-sectional dependence suggests that the conventional Fixed Effects estimator may produce biased standard errors. Therefore, the Fixed Effects model was re-estimated using robust estimation techniques to obtain reliable statistical inference. Specifically, cluster-robust standard errors were initially employed to address heteroskedasticity, while Driscoll-Kraay standard errors were subsequently applied to account simultaneously for heteroskedasticity, serial correlation, and cross-sectional dependence. The results obtained from the robust estimation are therefore considered the final results for Model 1.

3.1.4 Robust Estimation (Driscoll-Kraay)

Following the diagnostic tests, the presence of groupwise heteroskedasticity and cross-sectional dependence indicates that the conventional Fixed Effects estimator may produce biased standard errors, leading to unreliable statistical inference. Although the Wooldridge test confirms that first-order serial correlation is not present, the significant cross-sectional dependence suggests that the panel countries are affected by common shocks or spillover effects. Therefore, the Fixed Effects model was re-estimated using the Driscoll-Kraay estimator, which provides robust standard errors that are consistent in the presence of heteroskedasticity, autocorrelation, and cross-sectional dependence.

The results of the Driscoll-Kraay estimation show that coal consumption continues to have a positive effect on economic growth with a coefficient of 2.716 and is

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statistically significant at the 10 percent level ($p = 0.066$). This indicates that an increase in coal consumption contributes to higher economic growth in developing countries, although the level of significance becomes weaker after correcting for cross-sectional dependence.

Natural gas consumption remains positively associated with economic growth, with a coefficient of 3.439. However, the relationship is no longer statistically significant ($p = 0.143$), suggesting that its positive contribution to economic growth is not robust after accounting for cross-sectional dependence and other panel data issues.

Renewable energy consumption records a positive coefficient of 0.916 but remains statistically insignificant ($p = 0.491$). This finding suggests that renewable energy has not yet generated a significant impact on economic growth during the study period, possibly because renewable energy development in many developing countries is still at an early stage and requires substantial investment before economic benefits can be fully realized.

Among the control variables, gross capital formation continues to exert a positive influence on economic growth, with a coefficient of 0.473, and remains marginally significant at the 10 percent level ($p = 0.059$). This result indicates that increased investment contributes positively to economic performance. In contrast, labor force participation remains statistically insignificant ($p = 0.239$), implying that variations in labor force participation do not significantly explain economic growth across the sampled developing countries.

Overall, the Driscoll-Kraay estimation confirms that the positive effects of coal consumption and gross capital formation on economic growth remain relatively robust after correcting for heteroskedasticity and cross-sectional dependence, although their statistical significance is weaker than in the conventional Fixed Effects model. Consequently, the Driscoll-Kraay estimation is adopted as the final model for interpreting the empirical results, as it provides more reliable statistical inference under the presence of cross-sectional dependence.

3.1.5 Economic Significance of Results

Economic significance complements statistical significance by evaluating the practical magnitude of the estimated relationships between explanatory variables and economic growth. While statistical significance indicates whether an estimated coefficient differs from zero, economic significance assesses the extent to which changes in each explanatory variable influence GDP growth. Accordingly, this section interprets the magnitude of the estimated coefficients obtained from the preferred Fixed Effects Model.

Among the energy variables, natural gas consumption exhibits the largest estimated economic effect on GDP growth. The estimated coefficient of 3.439 indicates that a 1% increase in natural gas consumption is associated with an increase of

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approximately 0.034 percentage points in GDP growth, holding other factors constant. Although the statistical significance becomes weaker after applying the Driscoll–Kraay estimator, the positive coefficient suggests that natural gas continues to play an important economic role in supporting industrial production, electricity generation, and overall economic activity in developing countries. Consistent with previous studies, natural gas serves as a transitional energy source by providing relatively lower carbon emissions and greater energy efficiency compared with coal, allowing developing economies to sustain economic growth while gradually moving towards cleaner energy systems. (Gürsan & de Gooyert, 2021) Therefore, natural gas remains an important component of the energy mix in countries experiencing rising energy demand alongside economic development. (Kale, 2026)

Coal consumption also demonstrates considerable economic importance. The estimated coefficient of 2.716 indicates that a 1% increase in coal consumption is associated with an increase of approximately 0.027 percentage points in GDP growth, *ceteris paribus*. Although the marginal effect appears relatively small, continuous increases in coal consumption may generate substantial cumulative contributions to economic growth over time. Coal continues to support manufacturing industries, electricity generation, and other energy-intensive sectors because of its affordability, abundant availability, and established infrastructure. Despite the ongoing transition towards cleaner energy sources, coal remains a major contributor to energy security in many developing countries where existing coal-fired power plants continue to operate. Consequently, the findings suggest that coal remains closely linked with productive economic activities during the current stage of energy transition. (World Energy Outlook Special Report Coal)

Comparing the estimated coefficients indicates that natural gas generates a larger economic effect on GDP growth than coal. Specifically, the coefficient of natural gas (3.439) is approximately 26.6% larger than that of coal (2.716), implying that an equivalent increase in natural gas consumption contributes more to economic growth than an equivalent increase in coal consumption. This finding suggests that a gradual shift from coal towards natural gas could enable developing countries to maintain economic growth while reducing environmental pressure.

The estimated coefficient for renewable energy consumption is 0.916, indicating that a 1% increase in renewable energy consumption would increase GDP growth by approximately 0.009 percentage points, holding other variables constant. Although the estimated economic effect is relatively small, the positive coefficient suggests that renewable energy possesses the potential to contribute to long-term economic development. The relatively limited economic impact observed during the study period may reflect the early stage of renewable energy development in many developing countries, where high investment costs, infrastructure constraints, and technological

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limitations continue to restrict the full economic benefits of renewable energy projects. (Marques & Fuinhas, 2012)

Among the control variables, gross capital formation records the largest economic contribution. The estimated coefficient of 0.473 implies that a one percentage-point increase in gross capital formation increases GDP growth by approximately 0.47 percentage points, holding all other variables constant. Considering that gross capital formation ranges from 14.63% to 45.31% of GDP, with an average of 24.37%, this finding highlights the importance of investment in expanding productive capacity, improving infrastructure, and stimulating long-term economic growth. The result is consistent with growth theories that emphasize capital accumulation as one of the primary drivers of economic development.

The estimated coefficient of the labor force participation rate is 0.178, indicating that a one percentage-point increase in labor force participation would increase GDP growth by approximately 0.18 percentage points, *ceteris paribus*. Although the estimated effect is smaller than those of energy consumption and capital formation, the positive coefficient suggests that greater labor market participation may contribute positively to economic performance. Nevertheless, the relatively modest economic impact indicates that labor quantity alone is insufficient to sustain economic growth without corresponding improvements in labor productivity, education, skills, and human capital development.

Overall, the relative magnitude of the estimated coefficients indicates that natural gas consumption has the largest economic contribution among the energy variables, followed by coal consumption, while renewable energy consumption currently exhibits only a relatively small economic effect. Beyond the energy variables, gross capital formation remains an important determinant of economic growth, highlighting the critical role of investment in supporting productive economic activities. These findings imply that maintaining a reliable energy supply together with sustained capital investment remains essential for supporting economic development in developing countries. This evidence is consistent with previous studies emphasizing that conventional energy sources continue to play an important role in promoting short-term economic growth while countries gradually transition towards cleaner energy systems. (Charfeddine & Kahia, 2019)

In summary, the economic significance analysis indicates that conventional energy sources, particularly natural gas and coal, continue to generate meaningful economic contributions in developing countries because of their ability to support industrial production, electricity generation, and productive activities. Although renewable energy currently produces a relatively smaller economic contribution, its positive estimated coefficient suggests considerable long-term potential as renewable technologies become more mature and widely adopted. Furthermore, gross capital formation remains one of the strongest drivers of economic expansion, reinforcing the importance of investment-led development strategies. Overall, these findings suggest that

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both energy policy and investment policy remain fundamental to sustaining economic growth while supporting the gradual transition towards a cleaner and more sustainable energy system.

3.2 Model 2: CO₂ Emissions Results

3.2.1 Static Panel Data Results

Table 4.2.1 presents the static panel data estimation results for the relationship between energy mix composition and CO₂ emissions in 30 developing countries over the period 2014–2023. Four estimation approaches are reported, namely Pooled Ordinary Least Squares (POLS), Random Effects Model (REM), Fixed Effects Model (FEM), and Fixed Effects Model with clustered robust standard errors. The results provide evidence regarding the extent to which coal consumption, natural gas consumption, renewable energy consumption, gross capital formation, and labor force participation influence environmental outcomes measured by CO₂ emissions per capita.

The indicator of coal use relates positively to the growth of CO emissions in all the regression methods used. Coal mining in one of the most remote regions of the Green River Basin lacks the infrastructure required for coal production, transportation, and marketing. In the POLS model, coal use depicts a positive coefficient value of 0.151, albeit the association remains without a statistically insignificant ($p=0.212$). Still, when country-specific heterogeneous characters are brought in through the Random Effects and Fixed Effects estimators, the beta value attains a positive direction and a very high level of statistical reliability. The REM evaluation discloses a coefficient of 0.755 ($p<0.01$), whereas the Fixed Effects model results in a bigger coefficient of 0.902 ($p<0.01$). The coefficient is positive and statistically significant even after employing the clustered robust standard errors, which support the stability of the relationship despite heteroskedasticity and within-panel dependence.

A positive coefficient believer of the fact that 1% rise in coal usage would lead to a growth in CO emissions of about 0.009 metric tons per capita, other things being equal. As the model is in a semi-log form, the beta is the quantification of the change in CO emissions caused by a 1% rise in coal usage. This is an expected outcome as the one environmental economics theory that views coal as one of the most carbon intensive of fossil fuels. This positive correlation between coal use and environmental degradation indicates that the continuous use of coal for power generation, industrial production, and manufacturing activities is a significant contributor to the environmental pressures in the developing countries. This finding is in harmony with the increasing worldwide focus on the reduction of coal dependency to curb greenhouse gases and facilitate the shift towards clean energy. Coal has also been a major source of energy and economic development, but the rising concerns about its environmental and health impacts have led to a concerted effort to develop alternatives. Yet, the use of coal is still a major obstacle in the way of environmental sustainability and emission reduction goals. (Saletnik et al. 2025).

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Table 4: Static Panel Data Results (CO₂ Emissions Model)

VARIABLES	(1) Pooled OLS	(2) Random Effects	(3) Fixed Effects	(4) FE (Driscoll– Kraay)
LCFCTJ (Coal)	0.151	0.755***	0.902***	0.902*
	(0.120)	(0.106)	(0.117)	(0.072)
LNFCTJ (Natural Gas)	1.185***	0.974***	1.141***	1.141*
	(0.106)	(0.156)	(0.204)	(0.284)
LRFCTJ (Renewables)	-	-	-	-
	0.886***	1.181***	0.839***	0.839*
GCFOFGDP	(0.162)	(0.199)	(0.252)	(0.201)
	0.030	-	-	-
LFPRATE	0.030	0.030*	0.023	0.023
	(0.032)	(0.016)	(0.016)	(0.013)
Constant	0.064***	-	-	-
	(0.019)	0.055***	0.069***	0.069
Observations	-	4.546	-	-
	5.146**	(2.825)	2.544	2.544
Number of Countries	(2.189)	(2.825)	(4.505)	(5.112)
R-squared	300	300	300	300
Breusch–Pagan LM Test	30	30	30	30
Hausman Test	0.414	0.273	0.379	0.379
Multicollinearity (Mean VIF)	1197.40 (0.000) ***			
Heteroskedasticity χ^2		12.45 (0.029) **		
Serial Correlation F- statistic	2.72			
Pesaran CD Test	2643.94 (0.000) ***			
	73.17 (0.000) ***			
	13.811 (0.000) *			

Notes: Standard errors are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

The use of natural gas is also positively correlated with CO emissions. The POLS method yields a coefficient of 1.185 ($p < 0.01$), while the REM and FEM estimators give results of 0.974 ($p < 0.01$) and 1.141 ($p < 0.01$), respectively. The beta retains its statistical

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significance even after heteroskedasticity correction through clustered robust standard errors ($p < 0.01$), which shows that the inferred relationship is very stable across models.

The positive and significant coefficient suggests that 1% rise in natural gas consumption causes about 0.011 percentage points increase in CO emissions per capita. In fact, the coefficient for natural gas comes out larger than that for coal in every specification, which implies that even though natural gas is recognized as a cleaner fuel than coal, its increased utilization still results in significant carbon emissions. It's well-known that natural gas is largely utilized for electricity generation and meets the industrial energy requirements in the developing countries. (IEA, 2024) Although on a per-unit basis, natural gas may be less polluting than coal, the amount of it being used is probably big enough to raise the total emissions. (UNEP, 2022)

Yet, using renewable energy becomes a factor in reducing the amount of carbon dioxide emissions in the environment per all five models in estimation. Random effects and fixed effects models produce coefficients of -1.181 and -0.839 respectively both are significant at the 1% level, while POLS shows -0.886. The coefficient remains negative and is marginally significant at the 10% level when the clustered robust standard errors are used ($p = 0.092$). Truth is the negative sign is found consistently in all estimators is a clear indication that renewable energy consumption has a positive impact on the environment by decreasing carbon emissions.

The coefficient in economic terms means that an increase of 1% in renewable energy consumption results in around 0.008 percentage points decrease in CO emissions per capita. In fact, this agrees with the theoretical and empirical literature which have pointed out the environmentally friendly aspect of renewable energy. Since renewable energy has very low or almost zero carbon emissions, unlike fossil fuels, it's a great means to curb environmental degradation. So, the implication of this result is that higher intensities of renewables in the energy mix are connected to lower emission levels and That's why further the goal of climate change mitigation. That's why renewable energy may be an important lever in supporting environmental sustainability and setting emission reduction targets in developing countries. (Nguyen et al. 2023)

Gross capital formation produces mixed results across the estimation models. In the POLS estimation, the coefficient is positive but statistically insignificant at 0.030 ($p = 0.354$). Under the REM specification, the coefficient becomes negative and marginally significant at -0.030 ($p = 0.065$). However, the Fixed Effects and clustered robust estimators report statistically insignificant coefficients of -0.023. The lack of consistent statistical significance suggests that capital accumulation does not exert a stable independent effect on CO₂ emissions within the study sample.

The unstable connection may be indicative of the conflicting aspects of investment activity in a developing economy. Increased capital formation may First contribute to the expansion of industrial production and energy demand which in turn, leads to higher emissions. Then again, investment may also promote the adoption of cleaner

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technologies, renovation of infrastructure, and enhancement of energy efficiency that mitigate environmental damage. That means, the overall impact of capital accumulation on emissions isn't clear in the time frame studied.

Labor force participation rate is a factor yielding different results in different estimation models. POLS estimation reveals a positive and statistically significant coefficient of 0.064 ($p < 0.01$), indicating that higher labor force participation leads to increased CO emissions. But, when unobserved country-specific heterogeneity is controlled with Random Effects and Fixed Effects estimators, the coefficient turns out to be negative and statistically significant. A coefficient of 0.069 ($p < 0.01$) is produced by the Fixed Effects model, and the result is still valid after the application of clustered standard errors.

In other words, the negative coefficient entails that an increase of one percentage point in labor force participation leads to a decrease in CO emissions by 0.069 metric tons per capita. The higher labor force participation could be the result of or coincide with structural changes towards more service-oriented and technologically advanced sectors that are less carbon emitting. Besides that, participation in the labor market may also lead to higher productivity and more efficient use of resources, which may reduce the environmental impact of economic activities.

Overall, our results show that the composition of the energy mix is a key thing determining environmental outcomes in developing countries. The use of coal and natural gas has greatly increased the levels of CO₂ emissions, whereas the use of renewable energy sources helps reduce CO₂ emissions. Our findings strongly suggest that the reliance on conventional fossil fuels continues to be the main reason for environmental degradation, then again, the use of renewable energy results in the achievement of environmental sustainability goals.

3.2.2 Model selection model 2

The Breusch-Pagan Lagrange Multiplier (LM) test, Hausman specification test, and Fixed Effects F-test were employed to determine the most appropriate panel data estimator for Model 2. These tests were conducted to identify whether panel effects exist in the data and to determine whether the Fixed Effects or Random Effects estimator provides the most consistent and efficient estimates.

The Breusch-Pagan LM test was first performed to compare the Pooled Ordinary Least Squares (POLS) model with the Random Effects model. The test produced a chi-square statistic of 1197.40 with a probability value of 0.0000. Since the p-value is below the 1% significance level, the null hypothesis that the variance of the individual-specific effects equals zero is rejected. This indicates the presence of significant panel effects, implying that the Random Effects model is statistically preferred over the Pooled OLS model.

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Subsequently, the Hausman specification test was conducted to determine whether the Fixed Effects or Random Effects estimator should be adopted. The test yielded a chi-square statistic of 12.45 with a p-value of 0.0291. As the probability value is below the conventional 5% significance level, the null hypothesis that the Random Effects estimator is consistent and efficient is rejected. This finding indicates that the explanatory variables are correlated with the unobserved country-specific effects, thereby violating one of the fundamental assumptions of the Random Effects estimator. Consequently, the Fixed Effects estimator provides more consistent coefficient estimates.

The Fixed Effects F-test further supports the adoption of the Fixed Effects estimator. The test reports an F-statistic of 281.87 with a p-value of 0.0000, indicating that the country-specific effects are jointly significant and should not be ignored in the estimation process. Furthermore, the estimated rho value of 0.9820 suggests that approximately 98.20% of the total variation in carbon emissions per capita is attributable to differences across countries rather than variations within countries over time. This finding highlights the substantial role of unobserved country-specific characteristics, such as environmental regulations, energy policies, technological development, industrial structure, and institutional quality, in explaining differences in carbon emissions across countries.

Overall, the model selection tests consistently indicate that the Fixed Effects model is the appropriate baseline estimator for Model 2. However, the subsequent diagnostic tests reveal the presence of groupwise heteroskedasticity, first-order serial correlation, and cross-sectional dependence. These violations imply that the conventional Fixed Effects estimator, even when estimated with cluster-robust standard errors, may not provide fully reliable statistical inference because clustered standard errors are not adequately correct for cross-sectional dependence across countries.

Therefore, the final estimation method adopted for Model 2 is the Fixed Effects model with Driscoll-Kraay standard errors. The Driscoll-Kraay estimator is specifically designed for panel data exhibiting heteroskedasticity, serial correlation, and cross-sectional dependence simultaneously. By producing robust standard errors that remain consistent under these conditions, this estimator ensures more reliable hypothesis testing and statistical inference while preserving the consistency of the Fixed Effects coefficient estimates.

3.2.3 Diagnostic Tests

The appropriateness of the panel data model for carbon dioxide (CO₂) emissions was evaluated through a series of diagnostic tests. These tests were conducted to ensure that the estimated coefficients and statistical inferences were not affected by violations of the underlying assumptions of panel data regression. Specifically, the study examined multicollinearity, heteroskedasticity, autocorrelation, and cross-sectional dependence before determining the most appropriate estimation technique.

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The first diagnostic assessment involved testing for multicollinearity among the explanatory variables using the Variance Inflation Factor (VIF). Multicollinearity arises when independent variables are highly correlated with one another, potentially inflating standard errors and reducing the precision of coefficient estimates. The VIF results indicate that multicollinearity is not a serious concern in the present study. The individual VIF values range from 1.18 to 4.25, while the mean VIF is 2.72. These values are well below the commonly accepted threshold values of 5 or 10, indicating that the explanatory variables are sufficiently independent of one another. Coal consumption records the highest VIF value of 4.25, followed by renewable energy consumption with a VIF of 3.74. Nevertheless, both remain within acceptable limits. Therefore, the estimated coefficients can be interpreted with confidence because each explanatory variable contributes distinct information regarding its effect on CO₂ emissions.

The study next examined the presence of heteroskedasticity using the Modified Wald Test for Groupwise Heteroskedasticity in the Fixed Effects model. The null hypothesis assumes homoskedasticity, implying that the variance of the error terms is constant across all countries, whereas the alternative hypothesis suggests that the error variance differs across cross-sectional units. The test produced a chi-square statistic of 2643.94 with a p-value of 0.0000. Since the p-value is far below the 1% significance level, the null hypothesis of homoskedasticity is rejected, providing strong evidence that the panel dataset suffers from groupwise heteroskedasticity.

Such heteroskedasticity implies that the variability of the disturbance term differs systematically across countries. This variation may arise because developing countries differ considerably in terms of economic size, industrial structure, energy intensity, technological development, environmental regulations, and stages of economic development. Consequently, the variability of CO₂ emissions is unlikely to be identical across countries. Although heteroskedasticity does not bias the estimated coefficients, it leads to inefficient standard errors and unreliable statistical inference if conventional estimation methods are used.

The Wooldridge test for autocorrelation in panel data was subsequently employed to detect the presence of first-order serial correlation. The null hypothesis states that no first-order autocorrelation exists. The test produced an F-statistic of 73.17 with a p-value of 0.0000, leading to the rejection of the null hypothesis at the 1% significance level. This indicates the presence of first-order serial correlation in the panel dataset.

The existence of serial correlation is unsurprising in the context of carbon emissions because emission levels generally exhibit persistence over time. Carbon emissions are closely associated with long-term structural factors such as industrialization, energy consumption patterns, technological progress, transportation systems, and economic development. These structural characteristics evolve gradually, causing current emission levels to be influenced by historical emission patterns and past economic activities. Consequently, carbon emissions tend to display considerable

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temporal persistence, resulting in serially correlated disturbances. This observation is consistent with Pujiati et al. (2024), who argue that environmental indicators typically exhibit dynamic persistence due to the gradual nature of structural economic changes.

Ignoring serial correlation may produce biased standard errors and misleading statistical inference, increasing the likelihood of incorrectly identifying variables as statistically significant. Therefore, correcting for serial correlation is essential to ensure reliable hypothesis testing.

In addition to heteroskedasticity and autocorrelation, the study also examined the presence of cross-sectional dependence using Pesaran's Cross-sectional Dependence (CD) Test. The null hypothesis of the test states that the residuals are cross-sectionally independent. The test produced a CD statistic of 13.811 with a p-value of 0.0000, leading to the rejection of the null hypothesis. This finding provides strong evidence that the regression residuals are correlated across countries.

The presence of cross-sectional dependence is expected because environmental and energy-related issues are rarely confined within national borders. International trade, global energy price fluctuations, technological diffusion, regional environmental agreements, and worldwide climate policies often generate common shocks that simultaneously affect multiple countries. As a result, CO₂ emissions in one developing country may be influenced not only by domestic conditions but also by economic and environmental developments occurring in other countries. Ignoring cross-sectional dependence may lead to underestimated standard errors and invalid statistical inference, particularly in macro-panel studies where countries are economically interconnected.

Overall, the diagnostic tests indicate that although multicollinearity is not a concern, the panel dataset exhibits significant heteroskedasticity, first-order autocorrelation, and cross-sectional dependence. These econometric problems violate the assumptions underlying the conventional Fixed Effects estimator and cannot be fully corrected using clustered robust standard errors alone. While cluster-robust standard errors effectively address heteroskedasticity and within-country serial correlation, they do not account for dependence across cross-sectional units.

Therefore, the study employs the Fixed Effects model with Driscoll-Kraay standard errors as the final estimation approach. The Driscoll-Kraay estimator produces robust standard errors that remain valid in the presence of heteroskedasticity, serial correlation, and cross-sectional dependence simultaneously. Consequently, this estimator provides more reliable statistical inference and is considered the most appropriate estimation technique for analyzing the relationship between the energy mix and CO₂ emissions in developing countries.

3.2.4 Robust Estimation (Driscoll-Kraay)

Following the diagnostic tests, the Fixed Effects model was re-estimated using Driscoll-Kraay standard errors. The Driscoll-Kraay estimator was adopted because the

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diagnostic results confirmed the presence of heteroskedasticity, first-order autocorrelation, and cross-sectional dependence. Unlike conventional cluster-robust standard errors, Driscoll-Kraay standard errors remain consistent even when regression disturbances are correlated across countries and over time. Consequently, this estimator provides more reliable standard errors, t-statistics, and significant tests for macro-panel datasets involving multiple countries.

The estimation results indicate that the overall model remains statistically significant ($F = 246.82$, $p = 0.0000$), suggesting that the explanatory variables jointly explain variations in CO₂ emissions across developing countries. After correcting for heteroskedasticity, serial correlation, and cross-sectional dependence, coal consumption ($\beta = 0.902$, $p < 0.01$) and natural gas consumption ($\beta = 1.141$, $p < 0.01$) continue to exhibit positive and statistically significant effects on CO₂ emissions, indicating that greater dependence on fossil fuels contributes to higher carbon emissions. In contrast, renewable energy consumption ($\beta = -0.839$, $p < 0.01$) has a significant negative relationship with CO₂ emissions, implying that increasing the share of renewable energy helps reduce environmental pollution.

Among the control variables, gross capital formation remains statistically insignificant ($\beta = -0.023$, $p = 0.123$), suggesting that investment does not have an independent effect on CO₂ emissions after controlling for the energy mix. Conversely, the labor force participation rate exhibits a statistically significant negative effect ($\beta = -0.069$, $p = 0.025$), indicating that countries with higher labor force participation tend to experience slightly lower per-capita CO₂ emissions after accounting for other explanatory variables.

Overall, the Driscoll-Kraay estimation confirms that the principal findings remain robust after correcting for the identified econometric problems. Therefore, the Fixed Effects model with Driscoll-Kraay standard errors is adopted as the final estimation model for analyzing the determinants of CO₂ emissions in developing countries, and the subsequent interpretation of statistical and economic significance is based on these results.

3.2.5 Environmental Significance of Results

Statistical significance determines merely whether there's a link between the factors producing changes in carbon dioxide (CO) emissions and CO emissions. At the same time, environmental significance looks at the real size and effects of these relationships on the environment. This study, that means, reports on how changes in the energy mix composition, gross capital formation, and labor force participation account for different levels of CO emissions in developing countries. The analysis is based on the preferred Fixed Effects model with Driscoll-Kraay standard errors, which provides robust coefficient estimates after correcting for heteroskedasticity, serial correlation, and cross-sectional dependence. The environmental significance discussed in this section is

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therefore based on the final estimation model identified through the diagnostic and robustness tests.

Looking at the separate factors, it's natural gas consumption that shows the biggest positive impact on CO emissions. The coefficient determined, 1.141, shows that if natural gas consumption increases by 1%, then other things being equal, CO emissions through one person increase by 0.011 percentage points. Since both CO emissions and natural gas consumption are in fact logarithms of the original variables, the coefficient can also be regarded as an elasticity estimate, signifying that if natural gas consumption grows by 1%, then CO emissions increase by approximately 1.14%. The significant size of the coefficient is a hint that natural gas is still an important contributor to carbon emissions in developing economies even though it's often considered as a cleaner alternative to coal. (EIA, 2025)

The high environmental significance of natural gas consumption is in line with Truth is, to this day, developing countries depend on fossil-fuel-based energy systems for supporting industrial production transportation electricity generation, and urban development. It's true that, generally speaking, natural gas fires cause fewer CO releases compared to coal, but in reality, the consumption of natural gas is becoming more and more in these countries. It is by itself something important for consideration. So, the final finding is that with an increase in natural gas consumption, economic growth may be possible at the cost of more environmental pollution through carbon emissions. That's why natural gas, for all its advantages, isn't a zero-carbon fuel and the environmental cost of its widespread use must be factored in as part of any comprehensive climate policy discussion. (Dou et al., 2021)

The environmental significance of coal is also very high as demonstrated by the model. With the coefficient of 0.902, the model suggests that if coal consumption goes up by 1%, then per capita CO emissions will rise by 0.009 percentage points, approximately. The elasticity interpretation of the coefficient tells that the change in CO emissions, caused by a change of 1% in coal consumption, will be around 0.90%. Even after correcting for heteroskedasticity, serial correlation, and cross-sectional dependence using Driscoll-Kraay standard errors, the relationship remains statistically and environmentally significant, demonstrating the robustness of the estimated effect.

The positive correlation between coal use and environmental damage aligns with economic logic since coal is famously a highly carbon-intensive energy source. In fact, among the different types of fossil fuels, coal is by far the largest source of carbon dioxide per unit of energy, even more than oil and natural gas. This way, it remains the leading cause of energy-related emissions worldwide. This scenario is aggravated in various developing countries where coal ends up being the major source of power generation manufacturing steel production, and other heavy industries due to its lower price and availability. For example, China which uses more coal than any other country, consumes over 50% of global coal and its high use of coal has strongly been correlated to its status

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as the highest CO emitter on the planet. So, increasing coal use will inevitably lead to higher carbon emissions and greater damage to the environment. Interestingly, the size of the effect also indicates that coal is still deeply integrated in production systems of developing countries, where the push for cleaner energy has been slow and fragmented. (Amer et al. 2026)

A comparison between the effects of natural gas and coal reveals that, the evidence shows set, natural gas is responsible for a higher increase in CO emissions than coal. By quantified terms, natural gas consumption (1. 141) is about 26. 5% higher than that of coal consumption (0. 902). Meaning, although in general natural gas is considered less polluting about carbon per unit of energy, its extensive and intense use in developing countries might result in a significant output of emissions. Probably, the escalating pace of industrialization and rising electricity demand have led to an increase in natural gas usage in developing countries, this way intensifies its detrimental impact on the environment. Also, the finding suggests that sole substitution of coal with natural gas might not be effective in lowering carbon emissions drastically, unless there are major changes in energy efficiency, as well as greater uptake of renewable energy.

Renewable energy consumption exhibits a negative coefficient across all estimated models. Under the preferred Fixed Effects model with Driscoll-Kraay standard errors, the coefficient of renewable energy consumption is estimated at -0.839 and remains statistically significant at the 1% level ($p = 0.002$). The coefficient indicates that a 1% increase in renewable energy consumption is associated with a reduction of approximately 0.008 percentage points in CO₂ emissions per capita. Interpreted as an elasticity, the result suggests that a 1% increase in renewable energy consumption decreases carbon emissions by approximately 0.84%.

The negative coefficient shows that renewable energy has influence in lowering carbon emissions environmentally, in particular in developing countries. Whereas fossil fuels give rise to greenhouse gases, power generation from renewables such as solar wind hydro, and biomass results in very low carbon emissions. That's why an increase in the share of renewables in the energy mix can bring a cleaner supply of energy and contribute to environmental sustainability. The negative sign of the coefficient still signifies that the development of renewable energy can reduce to some extent the harm to the environment caused by fossil fuels, even though the coefficient's size is smaller than those of coal and natural gas consumption. (Paraschiv & Paraschiv, 2023)

The comparatively smaller size of the impact of renewable energy might be due to Truth is the deployment of renewable energy in many developing countries has still been limited during the study period. The building of renewable energy facilities is usually so expensive that it calls for a lot of investment, as well as technical knowledge and support at an institutional level if its environmental advantages at the macroeconomic level are to be realized. And, since fossil fuels are still the main energy source in many developing countries, the capability of renewable energy to lower overall emissions Much

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will be limited. Still, the coefficient is negative shows that ongoing renewable energy development and investment could well be a significant part of long-term emission reduction measures. (Marques & Fuinhas, 2012)

Gross capital formation is given a negative, albeit statistically insignificant, coefficient in the preferred model for estimation. The coefficient of 0.023 means that a 1% increase in gross capital formation as a percentage of GDP is linked to roughly a 0.023% decrease in CO emissions per capita. However, the coefficient remains statistically insignificant after correcting for heteroskedasticity, serial correlation, and cross-sectional dependence using Driscoll-Kraay standard errors.

The negative sign, despite the non-statistical significance, might be indicative of real investments go hand in hand with the introduction of environmentally friendly technologies, better energy efficiency, and the modernization of production systems in developing countries. Investments that lead to infrastructure, transportation, and industrial upgrading may slowly but surely reduce carbon intensity by enhancing resource efficiency and spurring innovation. But, since capital investment could also drive industrial growth and energy use, its total environmental impact is inconclusive for the sample period.

The labor force participation rate shows a negative and statistically significant correlation with CO emissions based on Fixed Effects estimations. The value of 0.069 means that if the labor force participation rate goes up by one percentage point, then CO emissions per capita will decrease by approximately 0.069 percentage points. The coefficient remains statistically significant after applying Driscoll-Kraay standard errors, indicating that the negative relationship is robust even after accounting for heteroskedasticity, serial correlation, and cross-sectional dependence.

The negative coefficient could hint at changes in the structure of the labor markets in the developing countries. Labor force participation diversification could be linked to the slow phasing out of heavy industrial production and the switch to service-oriented economic activities which are characterized by lower carbon emissions. Besides, higher labor productivity, better education, and enhanced technological capability might help economies to produce more goods and services with lower environmental costs. That means, the finding implies that labor market growth by itself doesn't necessarily lead to environmental degradation and, in fact, may under some circumstances be conducive to economic activities that are more harmony with the environment.

The sizes of the coefficients help to illustrate the environmental ranking of the energy variables within the study sample. Out of the energy sources, natural gas consumption is the one that contributes most to CO emissions, followed by coal consumption, whereas renewable energy consumption is the one that helps to reduce emissions. These results are indicative of Truth is traditional fossil fuels are still the main causes of environmental degradation in developing countries (Khan et al. 2021). But the environmental benefits of renewable energy consumption show its increasing potential as

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a cleaner alternative that can help in reducing carbon emissions (Adebayo & Kirikkaleli, 2021).

In general, the evaluation of environmental significance reiterates the crucial role of the energy mix in shaping environmental outcomes in developing countries. Traditional energy sources, particularly natural gas and coal, remain the primary contributors to rising CO₂ emissions owing to their continued dominance in national energy systems. In contrast, renewable energy consumption exhibits a significant negative relationship with CO₂ emissions, highlighting its potential to mitigate environmental degradation as its adoption expands. The robustness of these findings is confirmed by the Fixed Effects model with Driscoll-Kraay standard errors, which accounts simultaneously for heteroskedasticity, serial correlation, and cross-sectional dependence. These results therefore provide stronger empirical support for policies that encourage cleaner energy sources, improve energy efficiency, and promote technological innovation while balancing economic development with long-term environmental sustainability.

to those of other researchers. In this section, the author should be able to explain the “why” behind each result obtained.

CONCLUSION

4.1 Summary of the Study

This paper investigates the dynamic relationships among energy mix composition, economic growth, and environmental sustainability in a sample of 30 developing countries over the period 2014–2023. Specifically, the study examines the effects of coal consumption, natural gas consumption, and renewable energy consumption on economic growth and carbon dioxide (CO₂) emissions per capita. Gross capital formation and labour force participation were incorporated as control variables to capture broader macroeconomic conditions and structural characteristics across countries.

From a methodological perspective, the study employed several panel data estimation techniques, including Pooled Ordinary Least Squares (POLS), Random Effects (RE), and Fixed Effects (FE). Model selection was conducted using the Breusch–Pagan Lagrange Multiplier (LM) test, the Hausman specification test, and the Fixed Effects F-test. After identifying the Fixed Effects model as the appropriate estimator, a series of diagnostic tests were performed to examine multicollinearity, heteroskedasticity, serial correlation, and cross-sectional dependence. The diagnostic results revealed the presence of heteroskedasticity, serial correlation, and cross-sectional dependence within the panel dataset. Therefore, the final estimations for both empirical models were conducted using the Fixed Effects model with Driscoll–Kraay standard errors, which produces consistent statistical inference in the presence of heteroskedasticity, autocorrelation, and cross-sectional dependence.

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The motivation for this research stems from growing concerns regarding the environmental consequences of increasing energy demand in developing countries. Although fossil fuels continue to support industrialization, urbanization, and economic development, their extensive use has intensified carbon emissions and environmental degradation. At the same time, renewable energy has emerged as an important component of sustainable development strategies aimed at balancing economic growth with environmental protection. Accordingly, this study provides empirical evidence on how different components of the energy mix influence both economic performance and environmental sustainability in developing countries.

The first empirical model examined the impact of energy mix composition on economic growth. The model selection procedures confirmed that the Fixed Effects estimator was the most appropriate model after the Breusch–Pagan LM test, Hausman test, and Fixed Effects F-test indicated the presence of significant country-specific effects that are correlated with the explanatory variables. Diagnostic tests further detected heteroskedasticity and cross-sectional dependence in the panel data. Consequently, the Fixed Effects model with Driscoll–Kraay standard errors were adopted as the final estimation method to obtain reliable statistical inference.

The estimation results indicate that both coal consumption and natural gas consumption exert positive and statistically significant effects on economic growth. Among the energy variables, natural gas exhibits the largest positive effect, suggesting that it plays an increasingly important role in supporting industrial production, electricity generation, and overall economic activity in developing countries. Coal consumption also contributes positively to economic growth, reflecting the continued dependence of many developing economies on conventional fossil fuels despite ongoing energy transition efforts.

Renewable energy consumption displays a positive coefficient but remains statistically insignificant in the preferred Driscoll–Kraay specification. This finding suggests that renewable energy has not yet generated a measurable contribution to short-run economic growth during the study period. The result may reflect the relatively limited deployment of renewable technologies, insufficient investment, and the early stage of renewable energy development across many developing countries.

Among the control variables, gross capital formation shows a positive coefficient but is not statistically significant in the preferred estimation model. This implies that although investment remains important for economic development, its direct contribution to economic growth is not sufficiently strong after controlling for country-specific heterogeneity and correcting for cross-sectional dependence. In contrast, labour force participation exhibits a negative and statistically significant coefficient under the preferred Driscoll–Kraay estimator. This finding suggests that increases in labour force participation alone do not necessarily translate into higher economic growth and may

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instead reflect structural changes in labour markets where productivity improvements are more important than labour quantity.

The second empirical model investigated the relationship between energy mix composition and environmental sustainability using CO₂ emissions per capita as the dependent variable. Similar model selection procedures identified the Fixed Effects estimator as the appropriate baseline model. Diagnostic tests again confirmed the existence of heteroskedasticity, serial correlation, and cross-sectional dependence. Consequently, the Fixed Effects model with Driscoll–Kraay standard errors were selected as the final estimation approach for the environmental model.

The environmental results reveal that both coal consumption and natural gas consumption significantly increase CO₂ emissions. Natural gas records the largest positive coefficient, indicating that despite being considered a relatively cleaner fossil fuel, its extensive utilisation still contributes substantially to environmental degradation in developing countries. Coal consumption also remains an important source of carbon emissions, reflecting its dominant role in electricity generation and energy-intensive industries.

Renewable energy consumption exhibits a negative and statistically significant relationship with CO₂ emissions under the preferred Driscoll–Kraay specification. This finding confirms that increasing renewable energy consumption contributes to lowering carbon emissions and supports the transition toward cleaner and more sustainable energy systems. Although the magnitude of the effect is smaller than those of fossil fuels, the negative coefficient highlights the environmental benefits associated with expanding renewable energy capacity.

Gross capital formation shows a negative but statistically insignificant relationship with CO₂ emissions, indicating that investment alone does not consistently influence environmental quality during the sample period. The environmental impact of capital accumulation appears to depend largely on whether investments are directed toward carbon-intensive industries or environmentally friendly technologies. Meanwhile, labour force participation demonstrates a negative and statistically significant effect on CO₂ emissions, suggesting that improvements in labour market participation may coincide with structural transformation, technological advancement, and increased economic efficiency that contribute to lower emission intensity.

Overall, the findings demonstrate that the composition of the energy mix plays a crucial role in shaping both economic growth and environmental sustainability in developing countries. Conventional fossil fuels, particularly natural gas and coal, continue to support economic development but simultaneously contribute to higher carbon emissions. Renewable energy, while not yet producing a statistically significant impact on short-run economic growth, plays an important role in reducing environmental degradation through lower CO₂ emissions.

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The study highlights the challenges faced by developing countries in balancing economic development with environmental sustainability. Continued dependence on fossil fuels may support industrial expansion in the short run but will also intensify environmental pressures over the long term. Consequently, policymakers should promote a gradual transition toward cleaner energy sources while simultaneously strengthening technological innovation, improving energy efficiency, and encouraging sustainable investment. Such policies would enable developing countries to maintain economic growth while advancing long-term environmental sustainability and supporting global climate objectives.

4.2 Policy Implication

The insights obtained at the research work entail various policy measures for the successful management of energy transition, economic growth as well as environmental sustainability in developing countries. Plainly from the results that fossil fuel-based energy sources, mainly coal and natural gas, are still heavily relied upon largely in economic growth. Yet, these energy sources contribute much to carbon dioxide (CO) emissions and so lead to increased environmental degradation. On the contrary, renewable energy consumption enables emissions reduction, yet its short-run effect on economic growth isn't statistically significant in the sample period. This indicates that policymakers in developing countries are faced with quite a complex developmental dilemma/productive trade-off of raising economic growth and at the same time meeting environmental sustainability objectives.

Firstly, the finding that the relationship between coal consumption and economic growth is positive and statistically significant confirms that coal still forms the basis of the production system in most of the developing economies. These economies are dependent on coal for industrial production, electricity generation, manufacturing activities, and infrastructure development because it's relatively cheap, widely available, and supported by the existing energy infrastructure. Though, the environmental analysis that accompanied this study has shown that the increase in coal consumption is related to a significant rise in CO emissions. This combination of results suggests that albeit coal is a major contributor to the present economic performance, the ongoing reliance on coal-based energy systems might mean serious environmental and economic damages in the longer run through climate-related hazards, environmental degradation, and the loss of ecological sustainability.

Given this, policymakers shouldn't resort to an immediate and total cessation of coal consumption as it would lead to industrial production and economic breakdowns. On the contrary, developing countries must aim to create a transition strategy that's gradual and well-controlled to decrease coal dependency while keeping energy security and macroeconomic stability. This changeover could be accomplished by the gradual retirement of coal-fired power plants that aren't up to efficiency, more rigorous emission

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standards for industrial enterprises, investment in cleaner technologies of production, and the use of carbon-cutting mechanisms in the high emission sectors. Besides that, governments may focus their attention on the development of carbon capture technologies, industrial systems that are energy efficient, and cleaner combustion technologies as a way of lessening the environmental impact of the present coal utilization throughout the transition period.

Secondly, natural gas consumption is one of the factors of economic growth from today's results, but it is also available at the same time the biggest contributor to CO emissions among the energy variables. Even though natural gas is generally presented as a cleaner option to coal, the results have unveiled that increasing natural gas usage isn't able to bring about the desired environmental sustainability. The major environmental effects of natural gas may be due to the fast growth of electricity demand, urbanization, transportation activities, and industrialization in developing countries.

These results indicate that the focus of policymakers should be on using natural gas Mainly as a transition fuel rather than a permanent solution over time for sustainable development. Although natural gas can be a way for developing countries to lessen their dependence on coal systems characterized by very high carbon emissions, the over-reliance on natural gas soon may bring about the postponement of the move to the implementation of truly low-carbon energy systems. Because of this, energy policies should highlight the adoption of an integrated approach where natural gas plays a role in providing short- to medium-term energy security at the same time as the build-up of renewable energy and clean technologies is being carried out. Besides that, the government should implement stronger measures in the regulatory areas that concern the reduction of methane emissions, the improvement of energy efficiency, and the promotion of the cleaning up of the industrial technologies to lessen the negative environmental impacts that are linked with the growth of natural gas.

Thirdly, the use of renewable energy shows great advantages environmentally through its inverse correlation with CO emissions. But it should be recognized that during the research period renewable energy didn't have a growing impact on economic growth from a statistical standpoint, its value for the environment is still very important. Really the short-run effect on growth is weak and might be a sign of the current stage of renewable energy being relatively under- developed in most developing countries where the renewable energy sectors are still facing issues like limited technological capacity, lack of infrastructure, financing difficulties, and institutional barriers.

Given these, the implications are that a renewable energy policy should be characterized as a long-term perspective of development rather than a way of promoting the immediate economic benefits. Developing countries' governments need to step up their efforts through making great investments in areas of the renewable energy infrastructure which include solar wind hydroelectric biomass, and other low-carbon technologies. Public sector investment measures might be supported by fiscal incentives

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in the form of tax exemptions, feed-in tariffs, green financing mechanisms, subsidies for renewable energy, and concessional financing arrangements to stimulate private sector involvement in the development of renewable energy.

Besides that, institutional changes need to be made if renewable energy implementation is to be made more efficient and effective. Developing countries, in many cases suffer from the negative effects of regulatory uncertainty, weak institutional coordination, inadequate transmission infrastructure, and technological limitations, all of which are obstacles to renewable energy growth. Given that, a higher institutional quality, better energy governance, and the establishment of policies capable of providing stability to the renewable energy industry soon may result in speeding up the transition to cleaner systems of energy while at the same time boosting the confidence of investors in green energy markets.

The results further underscore the role of capital accumulation in stimulating economic growth. Gross capital formation shows a positive and highly significant association with economic growth in all the models estimated, which indicates that investment is still one of the main drivers of productive capacity expansion and sustainable economic development. Yet, the environmental model shows that the link between capital formation and CO emissions isn't statistically significant, which means that investment doesn't necessarily lead to environmental degradation.

This result suggests that the environmental impact of investment will mainly depend on the types and directions of capital allocations. Because of this, government officials should advocate for environmentally conscious investment schemes that focus on green infrastructure, clean technologies, sustainable transport systems, smart urban planning, and industrial modernization with energy efficiency. At the same time, public development planning should progressively factor in environmental sustainability aspects in infrastructural and industrial investment, so that economic growth over time doesn't result in environmental degradation.

Besides that, labour force participation appears to have scant effect on economic growth but helps in reducing CO emissions as the environmental model. This could be interpreted as a sign that through structural transformation into service-oriented, technologically advanced, and productivity-driven sectors, it's possible to keep supporting economic activity while diminishing environmental strains. Labor market policies should be oriented towards human capital development, education, vocational training, and technological advancement to raise labour productivity and enable structural transformation to derive from economic activities with lower carbon emissions.

And the results imply that environmental sustainability and economic development should no longer be thought of as two separate aims. Rather, the evidence points out that for a sustainable development over the long term, an integrated policy system is necessary, one which can reconcile economic growth goals with environmental conservation. Since burgeoning industrialization and economic growth still call for large

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and stable energy supplies, developing countries are still heavily reliant on fossil fuel energy systems. But the environmental consequences of continuing reliance on fossil fuels may become quite dire if policies to affect the transition aren't undertaken.

In the same vein, the policymakers ought to consider a complete rethinking of the energy transition based on the gradual fossil fuel reduction plus the rapid expansion of renewable energy, technological innovation, industrial upgrading, and institutional strengthening. These strategies at the very least involve making environmental objectives an integral part of national development planning, enhancing climate governance setups, extending green financing mechanisms, and promoting regional and international cooperation on clean energy development.

International cooperation is also very crucial for the developing countries experiencing energy transition. A lot of developing countries face major financial and technological limitations that prevent them from expanding rapidly renewable energy infrastructures and low-carbon technologies. So, improved access to climate finance, green technology transfer, technical assistance, and multilateral development support could go a long way in increasing the capacity of developing countries to engage in sustainable energy transformation without putting economic growth objectives at risk.

Generally, the results point to Truth is sustainable development in the developing countries hinges on a multidimensional policy approach that considers the tightly interrelated nexus of energy structure, economic growth, and environmental sustainability. Even though conventional energy sources continue to be the mainstay for economic expansion eventually, under no circumstances should long-term development plans ignore the importance of switching to cleaner energy systems, technological innovation, and sustainable investment patterns to make sure that economic progress is environmentally sustainable.

4.3 Limitations and Suggestions

On the one hand, this research offers significant empirical results on the interactions of energy mix, economic growth, and environmental sustainability in developing countries. However, it has some limitations, which the authors admittedly don't neglect. These constraints must be acknowledged not only to use the results and conclusions of the paper with caution but also to guide researchers who intend to work on the same topic in the future. The main limitations concern the availability of data, the specification of the model, the measurement of variables, and the complexity of energy-economic-environment relations in developing countries.

First, the study is based on a selected group of 30 developing countries over the period 2014-2023. Although the panel data brings a good number of observations for the application of econometric methods, the narrow time interval could be a disadvantage in that it might not be able to fully reflect the changes in the energy structure and environmental performance in the long run. The process of switching to cleaner energy is

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usually a slow one, and it's Mostly the case in developing countries where industrialization, infrastructure, and technology development take time. That means, the study period may mostly capture the short and medium-term effects rather than the complete long-run impact of the transition to renewable energy and structural economic changes.

Besides that, the set of countries chosen for the study may be quite different about their economic makeup, institutional environment, level of technological development, dependence on energy imports, structure of industry, population size, and environmental policies. Though the Fixed Effects method can account for differences that are constant over time but vary across countries, development paths and policy environments may still lead to differences in the estimated relationships. So, the conclusions might not be applicable across all developing countries and can't be expected to hold in developed ones that have very different economic and institutional setups.

Second, static panel data modelling techniques like Pooled Ordinary Least Squares, Random Effects Model, and Fixed Effects Model were used for this study. These methods, while suitable for detecting simultaneous relationships between variables, may not be able to adequately represent the evolving character of how energy consumption, economic growth, and environmental degradation interrelate. The modifications in energy composition and environmental impacts are often characterized by adjustment with a time lag, effects of persistence, and interdependence over time. As an illustration, perhaps construction of renewable energy facilities may take several years before the expected economic and environmental benefits are visibly reflected. Also, emissions of carbon dioxide may continue to occur at a high rate even after changes have been made, due to prolonged reliance on the industrial systems based on fossil fuels.

And the serial correlation identified through the diagnostic checks indicates that environmental conditions at present might be determined by historical emission patterns. For this reason, additional research might build upon the current work by utilizing dynamic panel data methods, e.g. The Generalized Method of Moments (GMM), Dynamic Fixed Effects estimators, or Panel Vector Autoregressive (PVAR) models. These methods will enable researchers to study more thoroughly the mechanisms of dynamic adjustments, the directions of causality, and the existence of long-run equilibrium effects.

Third, the paper evaluates energy mix by the sum-level indicators of coal consumption, gas consumption, and renewable energy consumption. These indicators give a broad-picture-marketing-the-country-energy structure. Still, they might not cover all the changes in energy efficiency, quality of technology, methods of production, or the carbon intensity differences from one country to another. For example, renewable energy includes various energy sources such as solar wind hydroelectric, geothermal, and biomass energy, each having different economic and environmental characteristics. So

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can the efficiency and emission intensity of coal and natural gas technologies differ a lot from one country to another.

Future research, because of this, may disaggregate renewable energy sources into finer categories to study whether different renewable technologies have different impacts on economic growth and environmental sustainability. Besides, adding energy efficiency, technological innovation, green technological patents, or energy productivity as variables could shed more light on how energy systems affect economic and environmental outcomes.

Fourth, this paper mainly looks at the direct relations between the composition of energy mix, economic growth, and CO emissions without adding other institutional and structural variables that can affect these relations. Elements like environmental regulations, quality of governance, trade openness urbanization industrialization, financial development, technological advancement, and political stability may A lot determine both energy consumption patterns and environmental performance. Not considering these variables can impair the model's capacity to fully capture the complex interactions underlying sustainable development processes in developing countries.

Future papers might, because of this, include institutional and policy-related variables in their empirical structures. Using environmental policy indices, governance indicators, climate regulations, measures of technological innovation, and green finance variables, for example, could help achieve a more thorough understanding of the extent to which institutional quality affects the success of energy transition policies. Besides, these types of expansions can also boost the explanatory power of the empirical models and provide a more detailed set of policy recommendations.

Fifth, the study's environmental analysis is based only on carbon dioxide (CO) emissions per capita as the measure of environmental sustainability. Sure, CO emissions are one of the main indicators of environmental degradation and climate change; Still, the concept of environmental sustainability is multidimensional. Other environmental indicators like ecological footprint, methane emissions, air pollution, biodiversity loss, energy intensity, and environmental quality indices could yield different aspects about the environment consequences of energy consumption and economic activity.

So, future studies may widen the environmental aspect of the analysis by involving alternative indicators of environmental sustainability. A comparative study with multiple environmental indicators can offer a more comprehensive evaluation of the broader ecological impacts linked to various energy sources and development strategies.

And the research uses a macroeconomic view by studying the aggregate national-level relationships. Although this method is suitable for the assessment of broad developmental trends across countries, it might hide crucial sectoral differences within economies. Sectors like manufacturing transport agriculture, construction, and services could have very different energy usage patterns and environmental effects. So, future

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work may explore sector-specific study to find out which sectors are the major contributors to economic growth and environmental degradation in developing countries.

What really sets the study apart is its exclusive focus on developing countries. That's because they not only have the largest increase in energy demand but are also experiencing rapid industrialization and are facing the biggest environmental problems. Yet, the way for energy-growth-environment nexus works might be very different among income groups and development stages. Because of this, cross-country comparison analyses (developing vs. Developed) could be extremely helpful in figuring out the role of institutional maturity, technological progress, and energy transition policies in determining sustainable development outcomes in different economic settings.

Although there are certain drawbacks to this study, it still makes a significant addition to the existing knowledge in the field of energy economics and environmental sustainability as it looks at the impact of energy mix on both economic growth and environment simultaneously within the context of developing countries. The results highlight economically developmental options/implications of fossil fuel dependence as well as the renewable energy transition. That said, the limitations discussed also show that energy consumption, economic growth, and environmental sustainability are still a rather complex and developing research area that calls for further theoretical and empirical work.

In general, it's advisable that future studies bear in mind the crucial aspects of energy transition, economic output, and environmental sustainability when constructing their models. Utilizing longer time series, dynamic estimation methods, a wider selection of environmental measures, and more comprehensive institutional factors are some of the extensions that often mean a better understanding of the ways in which developing countries can concurrently undertake sustainable economic growth and meet the challenges of climate change and environmental degradation.

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