# Economic Growth and Environmental Sustainability: Analyzing the Dynamics of Greenhouse Gas Emissions in QUAD Countries

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**Abstract**

The global economy is confronted with challenges of promoting sustainable economic wealth while mitigating environmental degradation. Maintaining equilibrium holds particular urgency for the formation and success of strategic alliances in the Quadrilateral Security Dialogue (QUAD), which comprises the United States, Japan, Australia, and India, representing both developed and emerging economies. This examines the impact of economic growth (GDP) and control variables on greenhouse gas (GHG) emissions of the QUAD countries. To achieve this, a two-step system Generalised Method of Moments (GMM) approach is employed. The results reveal that GDP, financial development, and energy consumption significantly drive GHG emissions, suggesting that structural reforms are essential to redirect financial growth and energy use toward sustainable pathways. This study contributes valuable insights to policy discussions focused on finance, trade, and energy reform to achieve sustainable growth by providing specific factors influencing GHG emissions in a strategic alliance of diverse economies.

**Keywords:** Greenhouse gas emissions, QUAD, System GMM, Natural Resource Rent, Economic Growth

**JEL Code**: F64, O47, Q56, Q57

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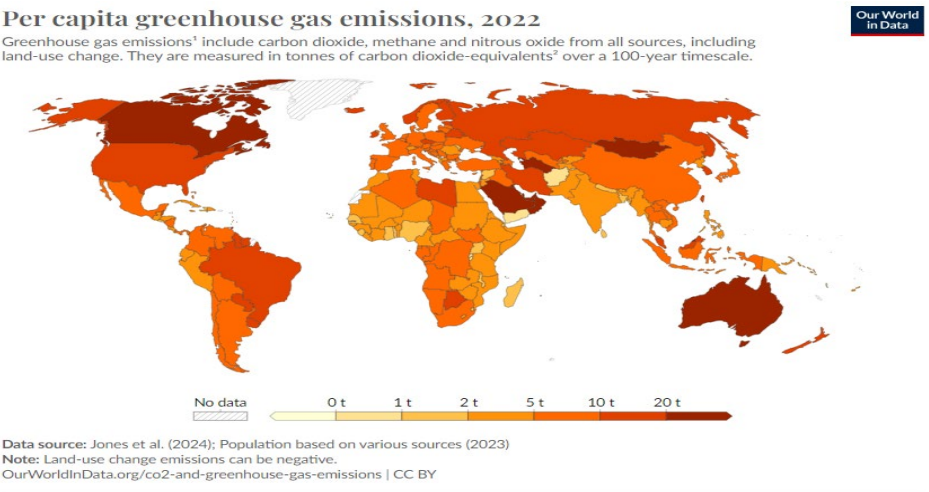
## 1. Introduction

The global economy is facing the dual challenge of driving economic growth in parallel to mitigating environmental degradation (Figure 1). For improving living standards and fostering economic development, wealth generation is essential, which often comes at a significant cost, including aggravating climate change. However, it leads to harmful effects on the environment, public health, and overall quality of life. Realisation of these effects has led to an exponential increase in studies that discuss the impact of different drivers of emissions (Wang et al., 2023). The issue of rising ecological footprints has consistently hindered the progress of sustainable development. As it is connected with a range of environmental concerns, i.e, climate change, global warming, deforestation, water shortage, pollution, and multiple health issues. The growing concern over greenhouse gas emissions, which are expected to reach their highest point in 2030, has made it necessary for economies to identify the determinants that contribute to emissions and therefore develop policies to achieve carbon neutrality (Daga et al., 2024; Sadiq et al., 2024). Meeting the targets of net-zero emissions, along with promoting sustainable growth, is the main motive around the globe. To accomplish the dual objectives, it is essential to determine the antecedents of greenhouse gas emissions to mitigate their consequences.




Source: Jones et al. (2024); population based on various sources (2024) with major processing by Our World in Data.

**Figure 1: Global Carbon Emissions**

In the last 50 years, economies have encountered challenges in addressing the environmental concerns arising from the increasing level of emissions. Much research has been conducted to comprehend the factors that lead to an increase in carbon footprints to identify effective policies to limit their impact, and to effectively address the issue of environmental degradation (Ulucak et al., 2020). However, there is no consensus on the factors that significantly influence emissions, whether positively or negatively. Results of the studies are found to be heterogeneous, and that is the main literature gap being addressed in the study. The literature remains divided, with variations across the methodology being used and the study period undertaken (Bekun et al., 2019; Opoku Marfo et al., 2023; Wang et al., 2024). However, one thing that has been common over the years in the research domain is that researchers have shown increasing interest in the determinants of greenhouse gas emissions. Evidence indicates various factors, such as an increase in energy demand, urbanisation, tourism, technological innovation, natural resources rent, and trade openness as significant determinants of greenhouse gas emissions, among others (Bekun et al., 2019; Li et al., 2024).

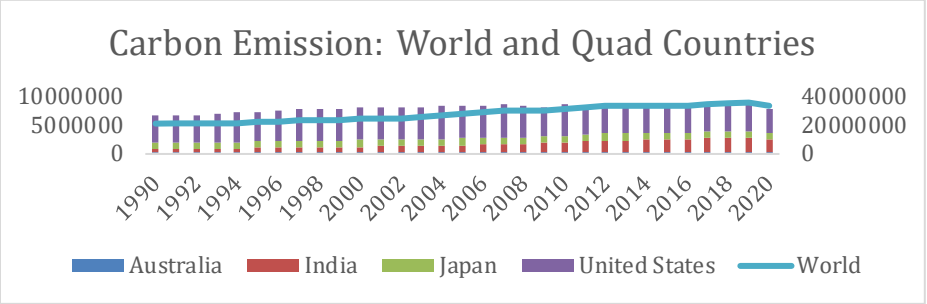
The relationship is, however, extremely dynamic as it does not follow a pattern and is mediated and moderated by several factors (Adebayo et al., 2022). Finding additional factors that can precisely reflect the intricate relationship between emissions and their underlying drivers serves as an important research gap that requires further investigation. Natural Resource Rent (NRR ) is one such factor that is said to possess a significant relationship with emissions (Bekun et al., 2019). Similarly, as an economy grows and opens up for trade, there is an increase in industrialisation, imports, and exports that can take a toll on emissions (Dou et al., 2021); however, another viewpoint is that increased trade can promote technical advancements that mitigate emissions. In addition to trade openness, which coincides with economic growth (Nguyen & Bui, 2021), another important determinant documented to impact emissions is financial development. Financial development and emissions are found to possess a bi-causal relationship wherein few studies highlight how financial growth helps an economy to make a shift toward energy efficiency, while others highlight the increased living standard and hence energy demand leading to greater emissions (Sadiq et al., 2024). Results for both trade and financial development are thus asserted to possess differing relationships depending upon the context, stage of economic development, and other macro and

micro-level factors that moderate the relationship. Another factor asserted to have a significant impact on emissions is gender diversity. It has shown mixed impact on the environment, where few studies assert that greater female representation in policymaking and population helps in promoting environment-friendly policies (McCright & Sundström, 2013) and hence reduced emissions, other studies indicate significant variations across regions, sectors, and firms. One significant gap observed in the previous studies on gender diversity and emissions is the predominant focus on board-level gender diversity, which emphasises corporate strategy and governance-related pathways for emission reduction. While this is important, it offers a limited perspective through which the gender-emissions relationship is evaluated. Recent research indicates that the female population in general plays a significant role in encouraging pro-environmental behaviour, particularly through household-level decisions, sustainable consumption patterns, and community engagement (Opoku Marfo et al., 2023). So, it is pivotal to understand the role of the overall female population that demonstrates the wider social impacts on environmental outcomes. Another two important factors that need due attention are energy usage and technological innovation. Both these factors are interlinked as an economy that spends on innovation leading to technological advancements, reduction of energy consumption, and mitigating emissions (Imran et al., 2022). Finally, the last factor that has experienced the effects of the environmentalists is the economic growth proxied by GDP. As proposed by the theory, when economies progress towards growth, they advance industrialization, resource utilisation, trade, and infrastructure enhancement, all of which result in substantial carbon footprints and emissions. Nevertheless, the effects and underlying causal mechanisms differ across all the economies and periods, as suggested by the Environmental Kuznets Curve, which indicates how economies move towards emission mitigation techniques after attaining a particular level of income (Dinda, 2004; Stern, 2004).

Although a significant amount of scholarly work has explored the relationship between economic growth and environmental emissions, major gaps persist in the existing literature. Much of the existing literature focuses on either advanced economies or particular geographic areas, tending to omit the distinct characteristics and complex linkages inherent in the strategic alliances such as the QUAD (Quadrilateral Security Dialogue) nations. Factors that influence greenhouse gas, like GDP, trade openness,

and energy consumption, have already been examined in a wide range by existing scholars. However, studies focusing on natural resource rent, gender diversity, and financial development within a multivariate framework are sparse. In addition, the existing literature often overlooks the heterogeneity in the impact of these determinants across countries at different stages of development. This study seeks to fill these gaps by conducting a comprehensive analysis of the QUAD countries to examine the nuanced and dynamic relationship between economic growth, financial development, and environmental sustainability. The research has chosen to utilize greenhouse gas emissions as a proxy for environmental sustainability, which is our dependent variable, instead of just focusing on carbon dioxide emissions. This decision was made since greenhouse gas emissions include all gases, including $CO_2$, that lead to environmental deterioration and, therefore, climate change.

To identify the prominent determinants of greenhouse gas emissions, the study considers the QUAD alliance of countries, QUAD. It has a unique mix of developed and emerging economies that not only contribute significantly to the global economic wealth (33% in 2023, World Bank) but also emit proportionately higher levels of greenhouse gases (Figure 1). The QUAD is an informal strategic forum that covers diverse economies, namely, the United States, India, Australia, and Japan, to address regional security matters, defense collaboration, and shared obstacles within the Indo-Pacific area. The group is a strategic alliance that exhibits features of both developed (USA, Japan, Australia) and emerging economies (India), along with covering the most carbon-emitting nations (India and the United States). The level of emissions by the alliance vis-à-vis the global emissions is highlighted in Figure 2.




Source: databank.worldbank.org

**Figure 2: Carbon Emission by QUAD countries vis-à-vis Global Emission**

To assess the relationship, the study has used a panel data estimation model that captures the dynamic interrelationship, along with handling the inherent data problems of endogeneity and serial correlation. The study employs the first difference system GMM model to identify the key determinants influencing GHG emissions across the QUAD countries. The analysis provides for a positive and significant influence of GDP on GHG emissions, and a 1% increase in the same brings a 2.62% change in emissions in the QUAD countries. Similar to GDP, even financial development and energy use significantly increase the level of emissions and, therefore, require structural reforms in the financial systems towards green financing and renewable sources of energy. Contrarily, natural resource rent and gender diversity contribute to a reduction in emissions, thereby calling for policy initiatives to enhance both to reduce emissions. The results can thus help in formulating policies in the domain of finance, trade, energy usage, research, and development, thereby helping the countries attain sustainable growth.

The study is organized into five sections, including an introduction. Section 2 furnishes an extensive literature review, while Section 3 elaborates data and method. Section 4 reports empirical results, and Section 5 consists of the conclusion, implications, and future scope of study.

## 2. Theoretical Background and Literature Review

Economies around the world are working hard to create wealth while sustaining the environment. Rising income levels require increased energy consumption, extraction of natural resources, increased production, and increased emissions (Fan et al., 2023). One of the initial studies that focused on macroeconomic factors and their impact on rising emissions is the EKC-Environment Kuznets Curve (Grossman & Krueger, 1991). The theory established a non-linear relationship between economic growth and environmental degradation. The relevance of the EKC and its associated literature is underscored by Ajmi et al. (2023), who conducted a literature review of the same and noted its prominence in the domain of sustainable development. According to the theory, as an economy transitions through its development phase, it undergoes industrialization and urbanization, which increase energy usage and the extraction of resources, thereby leading to increased emissions. However, after a certain income level, there is a transition towards green energy sources that brings a positive impact of income on the environmental quality, hence giving the relationship an

inverted U-shape (Voumik et al., 2023; Alfaisal et al., 2024; Li et al., 2024). Similar results are obtained by Udeagha & Muchapondwa (2023) on the BRICS economies for the period 1990-2020, supporting the EKC hypothesis. Further, Ganda & Ruza (2025) reported a U-shaped relationship between economic growth and emissions in BRICS and G7 economies, offering evidence that contradicts the traditional inverted U-shape of the EKC hypothesis. Similarly, Destek et al. (2018) asserted the presence of a U-shaped relationship between real income and ecological footprints, considering the data from 1980 to 2013. We documented the extensive literature reviews variable-wise appended below:

### *2.1 Natural Resource Rent, Trade Openness, and Emission Nexus*

One of the contemporary variables that is considered to be an antecedent of emission is the Natural Resource Rent (NRR) introduced by Bekun et al. (2019). It explains the emissions specifically in the growing economies, the reason being that such economies, for their industrialization, often rely on the extraction and usage of natural resources. The use of natural resources has a twin impact of generating wealth on one hand and leading to increased ecological footprints on the other (Udeagha & Muchapondwa, 2023). An in-depth analysis of the literature provided support for the positive linkage between natural resource rent, carbon emission, and environmental degradation (Zhang et al., 2023). The study was extended by Ulucak et al. (2020) in the OECD economies, wherein they used the Augmented mean group model to assert a positive impact of NRR on emissions. The results are supported by Sibanda et al. (2023) for the Sub-Saharan economies, Shen et al. (2021) for the 30 provinces of the Chinese economy, Ibrahim & Ajide (2021), and Ganda (2022) for BRICS The results, however, are not uniform when different interaction terms are used. Even for the same group of countries, the relationship varies as disclosed by Tufail et al. (2021), wherein the study asserted a negative relationship between NRR and carbon emissions for the period 1990-2018, which asserted how NRR helped in enhancing environmental quality. Li et al. (2024) used panel quantile regression to test the relationship in 38 countries and concluded that the impact differs based on different variables used in the analysis. Literature thus provides that in addition to NRR, various other factors mediate the NRR and emission nexus.

In recent decades, global wealth has risen significantly, coinciding with increased globalization. This trend has facilitated the movement of goods,

services, and human capital across nations. The pioneering research in the domain of trade openness and its relationship with global emissions was conducted by Grossman & Krueger (1991). The addition of variables in the EKC equation is to satisfy the Pollution Haven hypothesis along with sorting the problem of omitted variable bias in the EKC hypothesis (Q. Wang, et al., 2024). Amongst the various viewpoints that explain the nexus, one viewpoint is that Trade openness leads to increased trade across countries and increases energy consumption and hence emissions (Dou et al., 2021).

### *2.2 Financial Development, Gender Diversity, and Emission Nexus*

Financial development (FD) is a recent addition to the list of variables projected to lead to rising emissions. The findings, however, are inconclusive since some studies indicate a positive correlation, while others reveal a detrimental influence of FD on GHG emissions. Financial sector development is an important factor that enhances economies' overall growth, but at the same time, it also leads to environmental deterioration because of increased living standards and easy credit availability, which leads to increased demand for energy. The impact, however, can also be reversed if financial development leads to the use of better technology that promotes energy efficiency; in such a scenario, financial development helps protect the environment. Similar results are obtained by Zaidi et al., (2019) for the Asia Pacific Economic Cooperation (APEC) countries during the study period of 1990-2016, which asserted how financial development led to a decrease in emissions, and Huang et al. (2023) for the USA during the study period of 1995-2015. Further, Xing et al. (2017) documented how financial development led to improved emissions in the 30 provinces of China using panel ARDL.

Contrary results were obtained by Saidi & Mbarek, (2017) for 19 emerging economies during the period 1990-2013 wherein financial development led to decrease in environmental degradation, and also by Zhang (2011), who tested the impact of financial development on the level of emissions in China and highlighted how, over the study period, there has been a significant increase in emissions because of the increasing level of financial development in the country.

In addition to various macroeconomic variables discussed in the literature, an important determinant that is presumed to possess an intricate

relationship with environmental protection and emissions is gender diversity. Gender differences are found to have a significant impact on consumption patterns, along with the associated carbon footprints. Räty & Carlsson-Kanyama (2010) asserted that men contribute more towards carbon footprints because of a higher consumption of energy-intensive goods and services, while their gender counterparts are found to be more environmentally conscious and also engage in sustainable consumption practices. Other than taking steps towards environmental protection, gender diversity across boards also helps in better disclosure related to emissions (Paridhi & Arora, 2023). Gender diversity not only has an impact on personal consumption patterns but also impacts economies' environmental policymaking. However, the same results are not obtained for the emerging economy of Indonesia, wherein the study by Dwinajayanti & Olimsar (2024) concluded that gender diversity has no significant role to play in the disclosure of emissions during the study period. Most studies in the literature are focused on gender diversity across the boards and its impact on financial performance (Brahma et al., 2021) and emissions (Konadu et al, 2022). The wider impact of the female population as a whole on the macro-level emissions is still unexplored and requires further analysis. It thus led to the emergence of a research gap for the present study. The novelty of this study also lies in its use of overall gender diversity, measured at the population level, rather than the more commonly examined board-level or workplace gender diversity.

### *2.3 Energy Consumption, Technological Innovation, and Emission Nexus*

A critical issue that dampens emission mitigation is the trade-off that it shares with the growth prospects. A vast literature describes how economic growth is associated with increased energy consumption and rising emissions. The results, however, are not conclusive and vary based on the level of technical advancement, economic growth, and a shift toward cleaner energy sources. For instance, a study by Dogan & Turkekul, (2016) concluded that there is no confirmatory relationship between energy usage and emissions and the impact is found to be bi-directional in the USA for the period 1960-2010. Another study by Acheampong (2018) conducted in 116 countries using panel VAR provided varied results for different countries, wherein energy consumption was found to be positively associated with rising emissions in the MENA region but negatively related to sub-Saharan Africa and Caribbean-Latin America.

The technological innovation plays a pivotal role in mitigating carbon emissions and hence fostering sustainable development (Xiong & Dai, 2023). The existing literature highlights this association by investigating both its benefits and complexities, demonstrating how technological innovation can reduce emissions and promote sustainable development (Imran et al., 2022; Madaleno et al., 2022). The developing economies are found to deliver limited results because of inadequate infrastructure and regulatory frameworks (Razzaq et al., 2023). To strengthen the role of innovation in promoting environmental sustainability, further investigation into these influencing elements is essential.

The literature reviewed above offers an in-depth evaluation of existing research across various national contexts and sheds light on several unresolved questions that merit further investigation. The research gap has been addressed in the present study, wherein the extended EKC is being tested to identify the variables that have a prominent impact on the emissions, especially in the QUAD nations. This study elaborates an overview of the emission-growth nexus across the QUAD countries following a system GMM approach. The results of the EKC studies are inconclusive, and one of the reasons for the same can be attributed to the omitted variable bias, which led to the addition of variables on the predictor side (Z. Khan et al., 2020). This section highlights the independent and control variables used in the study and their relevance in understanding the variable and emission nexus, thereby helping with policy formulation.

## 3. Data and Method

### 3.1 Data Description

We analyse the impact of economic growth on GHG emissions across the QUAD countries. Additionally, some select control variables are taken into consideration for empirical investigation. The QUAD countries (Australia, Japan, the United States, and India) are cross-sectional units, while the time period from 1980 to 2022 is used to create panel data. The annual data of examined variables is used in this study. The data has been collected from the World Bank's Database and Our World in Data. Table 1 furnishes the description of the variables:

**Table 1: Data description**

| Variable Name | Symbol | Explanation | Literature Support |
|---|---|---|---|
| **Dependent Variable** | | | |
| Greenhouse Gas Emission | GHG | GHG emissions per capita | (Ibeabuchi et al., 2022); (Brandenstein et al., 2023) |
| **Independent Variable** | | | |
| Gross Domestic Product | GDP | Economic output measured in constant 2015 US dollars | (Dogan et al., 2017); (Sikder et al., 2022) |
| **Control Variables** | | | |
| Natural Resource Rent | NRR | Percentage of GDP from total natural resource rents | (J. Huang & Guo, 2023) |
| Financial Development | FD | Proportion of domestic credit provided to the private sector relative to GDP | (Shen et al., 2021) |
| Trade Openness | TO | Ratio of total trade (imports + exports) to GDP | (Shahbaz et al., 2017) |
| Energy Consumption | EC | Per capita consumption of primary energy in kilowatt-hours | (Kasman & Duman, 2015) |
| Research & Development | R&D | Number of patents filed by both domestic and international residents | (Imran et al., 2022) |
| Gender Diversity | GD | Population, female (% of total population) | (Konadu et al., 2022; Opoku Marfo et al., 2023) |

Source: World Development Indicators from databank.worldbank.org, ourworldindata.org from https://ourworldindata.org/energy#explore-data-on-energy

### 3.2 Method

For empirical investigation, the generalized method of moments (GMM) is employed. It helps address issues such as endogeneity, unobserved heterogeneity, and autocorrelation effectively (Khan et al., 2020). The basic equation for panel modelling is given in equation 1. The variables are transformed into the first difference to ensure that the country-specific effects are taken care of. The study makes use of the first-differenced GMM technique, as it is suitable because it effectively takes care of the dynamic interactions between the variables by modifying the data to exclude fixed effects. To take care of endogeneity in the model, lagged values of the explanatory variables are used as instruments. In addition to this, the lagged differences are used in the level equation, which not only improves efficiency but also provides robustness to the model. The equation for the same is given below

$$E\left[\Delta \varepsilon it.\, Z_{i,t-s}\right] = 0 \; for \; s \geq 2 \quad (1)$$

Here, Z represents the instrument set.

For robustness check, the Sargan and Wald tests are considered to ensure the validity of instruments and the joint significance of the coefficients.

### 3.3 Pre-Estimation Diagnostics

For the Generalized Method of Moments (GMM) estimates to be considered reliable and efficient, specific conditions must be satisfied. One of the key requirements is the appropriateness of the instruments used in the model. Additionally, it is important to confirm that there is no serial correlation in the error terms. The Sargan test is commonly employed to assess the validity of the instruments, while the presence of serial correlation is evaluated through the Arellano-Bond tests for first-order [AR(1)] and second-order [AR(2)] autocorrelation in the residuals (Arellano & Bond, 1991). The basic GMM Model is appended below:

$$\Delta GHG_{it} = \beta_1 \Delta GDP_{it} + \beta_2 \Delta NRR_{it} + \beta_3 \Delta FD_{it} + \beta_4 \, \Delta TO_{it} + \beta_5 \, \Delta EC_{it} + \beta_6 \, \Delta R\&D_{it} + \Delta \varepsilon_{it} \quad (2)$$

The above equation is further modified to include the lag of the dependent variable as one of the explanatory variables to address the issue of

endogeneity, along with capturing the dynamic relationship. The equation is provided below:

$$\Delta GHG_{it} = \alpha + \beta_1 \Delta GDP_{it} + \beta_2 \Delta NRR_{it} + \beta_3 \Delta FD_{it} + \beta_4 \Delta TO_{it} + \beta_5 \Delta EC_{it} + \beta_6 \Delta R\&D_{it} + \Upsilon \Delta GHG_{i(t-1)} + \Delta \varepsilon_{it} \quad (3)$$

The equation above provides a basic GMM equation with greenhouse gas emission per capita as the dependent variable. $GHG_{it-1}$ represents lagged emissions necessary for estimating system GMM. GDP represents the economic growth measured at constant 2015 US$ of the sample countries, NRR is the natural resource rent measured as a percentage of GDP, TO refers to the trade openness as a percentage of GDP, UB is the level of urbanization measured as the ratio of urban population to total population, FD refers to the financial development of the economy that is proxied by Domestic credit to the private sector as a percentage of GDP (Dogan & Turkekul, 2016). GD is a contemporary variable that shows gender diversity as measured by females as a percentage of the total population (Opoku Marfo et al., 2023), EC is the primary energy consumption per capita in kWh/person, and R&D is the technological innovation measured by patent application (Imran et al., 2022). The coefficients obtained from the system GMM help in understanding the dynamic interaction between greenhouse gas emissions and various explanatory variables.

## 4. Results and Discussion

This section consists of empirical results derived from the employed econometric models. Prior to static and dynamic panel regression, the summary statistics and correlation matrix are documented in Table 2 and Figure 4, respectively. As regards descriptive statistics, we note that Gross Domestic Product is witnessed with a 0.032 mean value and 0.0265 standard deviation, which further suggests that economic growth is stable across the different observations. The mean value and standard deviation of NRR are 2.23 and 2.1, respectively, showing wide differences in the degree of natural resource dependency among the examined regions. The average (mean) of GHG emissions is 0.00032, with a standard deviation 0.0273, demonstrating relevant dispersion and thus the presence of both high and low emission scenarios. It infers a substantial variability among different economic and environmental contexts within the examined sample,

particularly highlighting significant differences in financial development (FD) and trade openness (TO).

**Table 2: Summary Statistics**

| Variables | Mean | Median | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| **GD** | 50.1 | 50.4 | 1.1 | 48.2 | 51.4 |
| **TO** | 28.2 | 26.7 | 10.6 | 8.93 | 55.8 |
| **FD** | 95.2 | 91.2 | 63.1 | 7.84 | 218 |
| **NRR** | 2.23 | 2.03 | 2.1 | 0.0125 | 13.4 |
| **RD** | 0.0372 | 0.0315 | 0.0999 | -0.618 | 0.571 |
| **GDP** | 0.032 | 0.0335 | 0.0265 | -0.0613 | 0.0905 |
| **GHG** | 0.00032 | 0.00156 | 0.0273 | -0.0985 | 0.0881 |
| **EC** | 0.0136 | 0.0145 | 0.0337 | -0.0919 | 0.125 |

Source: Authors' Computation

Further, the correlation matrix provides several key relationships that the variables have with each other. Turning to Figure 4, we note that the female population, urban population, and domestic credit are positively correlated with energy consumption and GDP; that is, as these variables increase in value, so do energy and economic output. In contrast, natural resource rents and population have low negative correlations with GDP and GHG, respectively. It implies that regions that are more dependent on natural resources and have larger populations may have lower economic growth and emissions. Thirdly, the interaction between strong energy usage and GHG emissions shows the environmental impact of energy usage. However, as a few variables, such as population, urbanization, and female population are the components of the same set, hence out of the three only the female population, which denotes gender diversity, is taken in the study for further analysis (Barroso et al., 2024).

Table 3 provides the result derived from the Hausman test which is employed to assess the suitability between fixed and random effects models. The p-value of the Chi-square test is less than 0.05, which indicates that the fixed effects model is consistent, as it considers the potential correlation between explanatory variables and unobserved individual-specific effects,

resulting in more consistent and dependable estimations. Consequently, the fixed effects model is chosen for our analysis.

**Figure 4: Correlation Matrix of constituent variables**

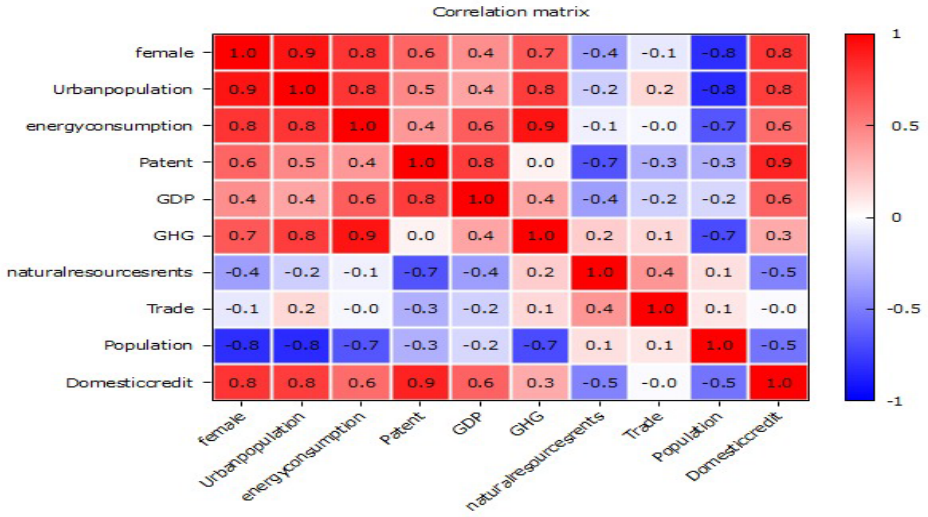



**Table 3(a): Results derived from the Hausman Test**

| **Summary** | **Chi-Square** | **DOF** | **Prob.** |
|---|---|---|---|
| Cross-Section Random | 14.985 | 7 | 0.0000*** |

***significant at 1% level

**Table 3(b)Fixed Effect Regression Model [Dependent variable -GHG emissions]**

| *Variable* | *Estimate* | *Standard Error* | *t-statistics* | *p-value* |
|---|---|---|---|---|
| Constant | −14.9690 | 20.4575 | −0.7317 | 0.5173 |
| GD | 0.24477 | 0.40346 | 0.6067 | 0.5869 |
| NRR | −0.0279515 | 0.02172 | −1.287 | 0.2884 |
| FD | 0.0006851 | 0.00202 | 0.3396 | 0.7565 |
| TO | 0.0003193 | 0.59654 | 0.00054 | 0.9996 |
| GDP | 0.990099 | 0.00176975 | 559.5 | 0.0001*** |
| EC | 7.13039 | 2.224 | 3.206 | 0.0491** |
| RD | −0.264103 | 0.24345 | −1.085 | 0.3574 |

*** and ** denote 1% and 5% significance level

Next, the result of the fixed effects model is encapsulated in Table 3(b), which demonstrates that GDP and EC affect GHG emissions positively and significantly. Since the fixed effects model does not consider the lag and may be biased due to endogeneity issues, we employ the generalised method of moments (GMM) model. The GMM handles uses instrumental variables and provides consistent estimates even in the presence of endogenous regressors. GMM can provide more efficient estimates by using moment conditions that account for these issues. We report the findings from the system GMM estimation along with diagnostic statistics that assess the robustness and appropriateness of the model in Table 4. The Sargan test is employed to check the validity of the instruments. If the Sargan test yields a significant p-value, it raises concerns about the instrument set, possibly indicating issues with model specification or instrument relevance.

Additionally, AR (1) and AR (2) demonstrate the presence (absence) of serial correlation in the error terms. A significant result in the AR (1) test is expected due to the construction of first differences, which naturally introduce first-order correlation. However, the AR(2) test result is more critical; here, a non-significant p-value indicates no second-order serial correlation, supporting the validity of the instruments and suggesting that the model is appropriately specified. Results of the system GMM identify the validity of the instruments (Sargan test) while establishing the significance of GDP, Natural resource rent, gender diversity, energy consumption, and financial development in impacting the emissions in the QUAD countries.

Results show how increasing GDP by 1% has a 2.62% increase in carbon emissions in the QUAD countries, showing how wealth generation has a direct and positive impact on emissions. The results are in a similar line with studies by Naseem & Guang Ji, (2021) and Sikder et al. (2022). Financial development is found to possess a positive impact on emissions, stating how an increase in them takes the economy away from sustainability, and hence a shift towards green sources of finance is what is required in the future (Sadiq et al., 2024; Zhou & Xu, 2022). Energy consumption is also having a positive and significant influence on rising emissions (Ganda, 2022), and it calls for making a shift towards green and renewable sources of energy. Similarly, natural resource rent is documented to assert a negative impact on emissions documenting the countries' efforts

towards environmental protection as is shown in the study by C. Wang et al. (2024). Gender diversity is also found to possess a negative impact on emissions, stating how the presence of diversity in the population, board, and policymaking can make a significant impact on reducing emissions, and hence calls for aggressive measures to look into this aspect.

Other variables, such as trade openness and research and development, although not found significant in the study, are important variables that have a theoretical impact on emissions, as stated in the literature. Study by Balsalobre-Lorente et al. (2023) For instance, it asserted a positive impact of ICT in reducing emissions. Also, the significance of certain variables like energy consumption and financial development in increasing emissions in the sample countries requires significant innovation to ensure that there is a move towards greener sources of energy and finance that can be done through policy formulations by the respective countries.

**Table 4: Results obtained from the Two-step System GMM model**

| Index | System-GMM Model | Implication |
|---|---|---|
| GHG(-1) | 0.9693*** (30.16) | Persistent effect over time |
| GDP | 2.6283** (2.190) | GDP → GHG ↑ |
| TO | 0.5748 (1.203) | No significant empirical relationship was established |
| FD | 0.0056* (1.667) | FD → GHG ↑ |
| NRR | −0.0637** (−2.083) | NRR → GHG ↓ |
| RD | 0.0637 (1.876) | No significant empirical relationship was established |
| GD | -0.8069* (-1.663) | GD → GHG ↓ |
| EC | 7.1993*** (4.098) | EC → GHG ↑ |
| Sargan Test | 60.1998 (0.1311) | Instruments are Valid |
| AR(1) | -5.0475*** (0.0000) | Autocorrelation exists |
| AR(2) | -0.9248 | Autocorrelation does not exist |

| | | |
|---|---|---|
| | (0.3550) | |

Source: Authors, Note: *** , **, *indicate 1%, 5%, and 10% significance level respectively

## 5. Conclusion, Implications and Future scope of study

QUAD countries, that is, a strategic alliance of Australia, India, Japan, and the United States, not only boast of a major chunk of global wealth but are also significant contributors to worldwide emissions. As these countries make use of more energy, they are expected to be the torchbearers for promoting policies that help in promoting sustainable growth.

We investigate the key drivers of GHG emissions within the QUAD nations over the period from 1980 to 2022. For empirical analysis, we deploy a two-step system GMM estimator. The results from the system GMM model reveal that past emission levels significantly influence current emissions, demonstrating the persistent nature of environmental degradation and the challenge of reversing emission trends. We observe a positive association between GHG emissions and variables like GDP, financial development, and energy usage, which implies that economic and financial growth, along with rising energy demand, contribute to higher emission levels. Further, a negative relation is found between natural resource rent and emissions, suggesting that countries with a high reliance on natural resources may adopt more proactive approaches to manage environmental impact. Additionally, the study finds a notable association between gender diversity and emissions, indicating that gender-inclusive policies and broader demographic dynamics could influence environmental outcomes.

The findings of the research provide important policy implications for the QUAD countries to facilitate strategic interventions in delinking economic growth from GHG emissions. Governments worldwide must move towards the adoption of green financial instruments and provide incentives for corporations to transition toward sustainable finance, ensuring that financial development is aligned with environmental objectives. Other than technological advancement and financial development, there needs to be gender diversity in decision-making bodies so that inclusive policies can be designed for environment-conscious decisions. The adverse effects of economic and energy consumption growth on the environment can be reduced if policymakers focus on investments in efficient energy technologies and promote the need for energy saving. Additionally, the

empirical findings have specific implications for policy and practice. The negative and significant impact of financial development on emissions suggests that expanding access to credit, especially for clean technologies, SMEs, and green infrastructure, can be an effective decarbonization strategy. Financial regulators in QUAD countries, particularly India, could promote green banking guidelines and sustainability-linked loans to scale such outcomes. Further, the positive association between trade openness and GHG emissions indicates the importance of embedding environmental standards within trade agreements, and of promoting the export of low-carbon technologies instead of carbon-intensive goods.

Though this study attempts to analyse the impact of economic growth on GHG, it is not without limitations. The world has witnessed drastic changes due to geopolitical issues and war since 2022. These issues affect the economic growth along with environmental sustainability. Additionally, these concerns are of developed as well as developing economies. On this note, further, the study may be extended by comparing the impact of economic growth on GHG between developed and developing economies based on the period of geopolitical hostility. Methodologically, a mean group (MG) panel and a pooled mean group (PMG) estimator may be employed for further empirical analysis.

## References:

Acheampong, A. O. (2018). Economic growth, CO2 emissions and energy consumption: What causes what and where? Energy Economics, 74, 677-692.
https://doi.org/10.1016/j.eneco.2018.07.022

Adebayo, T. S., Akadiri, S. S., Adedapo, A. T., & Usman, N. (2022). Does interaction between technological innovation and natural resource rent impact environmental degradation in newly industrialized countries? New evidence from method of moments quantile regression. Environmental Science and Pollution Research, 29(2), 3162-3169.
https://doi.org/10.1007/s11356-021-17631-y

Ajmi, A. N., Bekun, F. V., Gyamfi, B. A., & Meo, M. S. (2023). A bibliometric review analysis into environmental kuznets curve

phenomenon: A retrospect and future direction. Heliyon, 9(11), e21552. https://doi.org/10.1016/j.heliyon.2023.e21552

Alfaisal, A., Xia, T., Kafeel, K., & Khan, S. (2024). Economic performance and carbon emissions: Revisiting the role of tourism and energy efficiency for BRICS economies. Environment, Development and Sustainability, 0123456789. https://doi.org/10.1007/s10668-023-04394-4

Arellano, M., & Bond, S. (1991). Some Test of Specification for Data Panel: Monte Carlo Evidence and an Application of Employment Equations. Source: The Review of Economic Studies, 58(2), 277-297. https://doi.org/10.2307/2297968

Balsalobre-Lorente, D., Abbas, J., He, C., Pilař, L., & Shah, S. A. R. (2023). Tourism, urbanization and natural resources rents matter for environmental sustainability: The leading role of AI and ICT on sustainable development goals in the digital era. Resources Policy, 82(March). https://doi.org/10.1016/j.resourpol.2023.103445

Barroso, R., Duan, T., Guo, S. (Sarina), & Kowalewski, O. (2024). Board gender diversity reform and corporate carbon emissions. Journal of Corporate Finance, 87, 102616. https://doi.org/10.1016/j.jcorpfin.2024.102616

Bekun, F. V., Alola, A. A., & Sarkodie, S. A. (2019). Toward a sustainable environment: Nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. Science of the Total Environment, 657, 1023-1029. https://doi.org/10.1016/j.scitotenv.2018.12.104

Brahma, S., Nwafor, C., & Boateng, A. (2021). Board gender diversity and firm performance: The UK evidence. International Journal of Finance and Economics, 26(4), 5704-5719. https://doi.org/10.1002/ijfe.2089

Brandenstein, N., Ackermann, K., Aeschbach, N., & Rummel, J. (2023). The key determinants of individual greenhouse gas emissions in Germany are mostly domain-specific. Communications Earth and Environment, 4(1), 1-18. https://doi.org/10.1038/s43247-023-01092-x

Daga, S., Yadav, K., Lakshmi, V., & Singh, P. (2024). Growth vs. green: Unpacking the economic-environmental dilemma in major carbon emitters with panel ARDL analysis. Discover Environment, 2(1), 143. https://doi.org/10.1007/s44274-024-00173-8

Destek, M. A., Ulucak, R., & Dogan, E. (2018). Analyzing the environmental Kuznets curve for the EU countries: The role of ecological footprint. Environmental Science and Pollution Research, 25(29), 29387-29396. https://doi.org/10.1007/s11356-018-2911-4

Dinda, S. (2004). Environmental Kuznets Curve hypothesis: A survey. Ecological Economics, 49(4), 431-455. https://doi.org/10.1016/j.ecolecon.2004.02.011

Dogan, E., Seker, F., & Bulbul, S. (2017). Investigating the impacts of energy consumption, real GDP, tourism and trade on CO2 emissions by accounting for cross-sectional dependence: A panel study of OECD countries. Current Issues in Tourism, 20(16), 1701-1719. https://doi.org/10.1080/13683500.2015.1119103

Dogan, E., & Turkekul, B. (2016). CO2 emissions, real output, energy consumption, trade, urbanization and financial development: Testing the EKC hypothesis for the USA. Environmental Science and Pollution Research, 23(2), 1203-1213. https://doi.org/10.1007/s11356-015-5323-8

Dou, Y., Zhao, J., Malik, M. N., & Dong, K. (2021). Assessing the impact of trade openness on CO2 emissions: Evidence from China-Japan-ROK FTA countries. Journal of Environmental Management, 296(April), 113241. https://doi.org/10.1016/j.jenvman.2021.113241

Dwinajayanti, R., & Olimsar, F. (2024). Influence of Gender Diversity , Institutional Ownership , Environmental Performance , and Audit Committee on Carbon Emission Disclosure ( Empirical Study on Energy Sector Companies Listed on the Indonesia Stock Exchange in 2019-2022 ). 2(3), 1089-1103. https://doi.org/10.59653/ijmars.v2i03.876

Fan, K., Zheng, M., Shen, Y., & Zhang, F. (2023). Nexus between economic recovery, energy consumption, CO2 emission, and total natural resources

rent. Resources Policy, 87(PB), 104157. https://doi.org/10.1016/j.resourpol.2023.104157

Ganda, F. (2022). The nexus of financial development, natural resource rents, technological innovation, foreign direct investment, energy consumption, human capital, and trade on environmental degradation in the new BRICS economies. Environmental Science and Pollution Research, 29(49), 74442-74457. https://doi.org/10.1007/s11356-022-20976-7

Ganda, F., & Ruza, C. (2025). Unveiling the non-linear dynamics: Quantile regression of financial development's impact on environmental degradation in BRICS and G7 nations. Discov Sustain, 6(60). https://doi.org/10.1007/s43621-025-00792-y

Grossman, G. M., & Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement. 3914. https://doi.org/10.3386/w3914

Huang, J., & Guo, L. (2023). Analysis of the impact of natural resource rent, transportation infrastructure, innovation and financial development on China's carbon emission. Energy and Environment, 34(6), 1805-1825. https://doi.org/10.1177/0958305X221100526

Huang, S. Z., Sadiq, M., & Chien, F. (2023). The impact of natural resource rent, financial development, and urbanization on carbon emission. Environmental Science and Pollution Research, 30(15), 42753-42765. https://doi.org/10.1007/s11356-021-16818-7

Ibeabuchi, I. J., Amaefule, C., & Shoaga, A. (2022). Determinants of Greenhouse Gas Emissions. European Journal of Sustainable Development Research, 6(4), em0194. https://doi.org/10.21601/ejosdr/12176

Ibrahim, R. L., & Ajide, K. B. (2021). The dynamic heterogeneous impacts of nonrenewable energy, trade openness, total natural resource rents, financial development and regulatory quality on environmental quality: Evidence from BRICS economies. Resources Policy, 74(June), 102251. https://doi.org/10.1016/j.resourpol.2021.102251

Imran, M., Ali, S., Shahwan, Y., Zhang, J., & Al-Swiety, I. A. (2022). Analyzing the Effects of Renewable and Nonrenewable Energy Usage and

Technological Innovation on Environmental Sustainability: Evidence from QUAD Economies. Sustainability, 14(23), 15552. https://doi.org/10.3390/su142315552

Jones et al. (2024); Population based on various sources (2024) - with major processing by Our World in Data. "Per capita greenhouse gas emissions including land use" [dataset]. Jones et al., "National contributions to climate change 2024.2"; Various sources, "Population" [original data]. Retrieved April, 2024 from https://archive.ourworldindata.org/20250925-233948/grapher/per-capita-ghg-emissions.html (archived on September 25, 2025).

Kasman, A., & Duman, Y. S. (2015). CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis. Economic Modelling, 44, 97-103. https://doi.org/10.1016/j.econmod.2014.10.022

Khan, A., Chenggang, Y., Hussain, J., Bano, S., & Nawaz, Aa. A. (2020). Natural resources, tourism development, and energy-growth-CO2 emission nexus: A simultaneity modeling analysis of BRI countries. Resources Policy, 68(May), 101751. https://doi.org/10.1016/j.resourpol.2020.101751

Khan, Z., Ali, M., Jinyu, L., Shahbaz, M., & Siqun, Y. (2020). Consumption-based carbon emissions and trade nexus: Evidence from nine oil exporting countries. Energy Economics, 89, 104806. https://doi.org/10.1016/j.eneco.2020.104806

Konadu, R., Ahinful, G. S., Boakye, D. J., & Elbardan, H. (2022). Board gender diversity, environmental innovation and corporate carbon emissions. Technological Forecasting and Social Change, 174(October 2021), 121279. https://doi.org/10.1016/j.techfore.2021.121279

Li, R., Wang, Q., & Guo, J. (2024). Revisiting the Environmental Kuznets Curve (EKC) Hypothesis of Carbon Emissions: Exploring the Impact of Geopolitical Risks, Natural Resource Rents, Corrupt Governance, and Energy Intensity. Journal of Environmental Management, 351(November 2023), 119663. https://doi.org/10.1016/j.jenvman.2023.119663

Madaleno, M., Dogan, E., & Taskin, D. (2022). A step forward on sustainability: The nexus of environmental responsibility, green

technology, clean energy and green finance. Energy Economics, 109(November 2021), 105945.
https://doi.org/10.1016/j.eneco.2022.105945

McCright, A. M., & Sundström, A. (2013). Examining Gender Differences in Environmental Concern in the Swedish General Public, 1990-2011. International Journal of Sociology, 43(4), 63-86.
https://doi.org/10.2753/IJS0020-7659430402

Naseem, S., & Guang Ji, T. (2021). A system-GMM approach to examine the renewable energy consumption, agriculture and economic growth's impact on CO2 emission in the SAARC region. GeoJournal, 86(5), 2021-2033.
https://doi.org/10.1007/s10708-019-10136-9

Nguyen, M. L. T., & Bui, T. N. (2021). Trade openness and economic growth: A study on asean-6. Economies, 9(3). https://doi.org/10.3390/economies9030113

Opoku Marfo, E., Kwakwa, P. A., Aboagye, S., & Ansu-Mensah, P. (2023). The role of female population, urbanization and trade openness in sustainable environment: The case of carbon dioxide emissions in Ghana. Cogent Economics and Finance, 11(2).
https://doi.org/10.1080/23322039.2023.2246318

Paridhi, & Arora, A. (2023). Sustainability reporting: Current state and challenges. Business Strategy and Development, 6(3), 362-381.
https://doi.org/10.1002/bsd2.244

Räty, R., & Carlsson-Kanyama, A. (2010). Energy consumption by gender in some European countries. Energy Policy, 38(1), 646-649.
https://doi.org/10.1016/j.enpol.2009.08.010

Razzaq, A., Sharif, A., Ozturk, I., & Skare, M. (2023). Asymmetric influence of digital finance, and renewable energy technology innovation on green growth in China. Renewable Energy, 202 (January 2023), 310-319.
https://doi.org/10.1016/j.renene.2022.11.082

Sadiq, M., Paramaiah, C., joseph, R., Dong, Z., Nawaz, M. A., & Shukurullaevich, N. K. (2024). Role of fintech, green finance, and natural

resource rents in sustainable climate change in China. Mediating role of environmental regulations and government interventions in the pre-post COVID eras. Resources Policy, 88(November 2023), 104494. https://doi.org/10.1016/j.resourpol.2023.104494

Saidi, K., & Mbarek, M. B. (2017). The impact of income, trade, urbanization, and financial development on CO2 emissions in 19 emerging economies. Environmental Science and Pollution Research, 24(14), 12748-12757. https://doi.org/10.1007/s11356-016-6303-3

Shahbaz, M., Nasreen, S., Ahmed, K., & Hammoudeh, S. (2017). Trade openness-carbon emissions nexus: The importance of turning points of trade openness for country panels. Energy Economics, 61, 221-232. https://doi.org/10.1016/j.eneco.2016.11.008

Shen, Y., Su, Z. W., Malik, M. Y., Umar, M., Khan, Z., & Khan, M. (2021). Does green investment, financial development and natural resources rent limit carbon emissions? A provincial panel analysis of China. Science of the Total Environment, 755, 142538. https://doi.org/10.1016/j.scitotenv.2020.142538

Sibanda, K., Garidzirai, R., Mushonga, F., & Gonese, D. (2023). Natural Resource Rents, Institutional Quality, and Environmental Degradation in Resource-Rich Sub-Saharan African Countries. Sustainability (Switzerland), 15(2). https://doi.org/10.3390/su15021141

Sikder, M., Wang, C., Yao, X., Huai, X., Wu, L., Kwameyeboah, F., Wood, J., Zhao, Y., & Dou, X. (2022). Science of the Total Environment The integrated impact of GDP growth , industrialization , energy use , and urbanization on CO 2 emissions in developing countries: Evidence from the panel ARDL approach. Science of the Total Environment, 837(February), 155795. https://doi.org/10.1016/j.scitotenv.2022.155795

Stern, D. I. (2004). The Rise and Fall of the Environmental Kuznets Curve. World Development, 32(8), 1419-1439. https://doi.org/10.1016/j.worlddev.2004.03.004

Tufail, M., Song, L., Adebayo, T. S., Kirikkaleli, D., & Khan, S. (2021). Do fiscal decentralization and natural resources rent curb carbon emissions? Evidence from developed countries. Environmental Science and Pollution

Research, 28(35), 49179-49190. https://doi.org/10.1007/s11356-021-13865-y

Udeagha, M. C., & Muchapondwa, E. (2023). Striving for the United Nations (UN) sustainable development goals (SDGs) in BRICS economies: The role of green finance, fintech, and natural resource rent. Sustainable Development, 31(5), 3657-3672. https://doi.org/10.1002/sd.2618

Ulucak, R., Danish, & Ozcan, B. (2020). Relationship between energy consumption and environmental sustainability in OECD countries: The role of natural resources rents. Resources Policy, 69(September), 101803. https://doi.org/10.1016/j.resourpol.2020.101803

Voumik, L. C., Sultana, R., & Dey, R. (2023). Going Away or Getting Green in BRICS: Investigating the EKC Hypothesis with Human Capital Index, Nuclear Energy, Urbanization, and Service Sectors on the Environment. World Development Sustainability, 2(February), 100060. https://doi.org/10.1016/j.wds.2023.100060

Wang, C., Zhou, D., Guo, X., & Kayani, U. N. (2024). Role of natural resource rents, financial development and technological research in achieving sustainable development: A study of South Asian Countries. Resources Policy, 89(July 2023), 104632. https://doi.org/10.1016/j.resourpol.2023.104632

Wang, Q., Li, Y., & Li, R. (2024). Rethinking the environmental Kuznets curve hypothesis across 214 countries: The impacts of 12 economic, institutional, technological, resource, and social factors. Humanities and Social Sciences Communications, 11(1), 1-19. https://doi.org/10.1057/s41599-024-02736-9

Wang, Q., Zhang, F., & Li, R. (2023). Revisiting the environmental kuznets curve hypothesis in 208 counties: The roles of trade openness, human capital, renewable energy and natural resource rent. Environmental Research, 216(P3), 114637. https://doi.org/10.1016/j.envres.2022.114637

World Bank. (2025). World Development Indicators. from https://databank.worldbank.org/source/world-development-indicators

Xing, T., Jiang, Q., & Ma, X. (2017). To facilitate or curb? The role of financial development in China's carbon emissions reduction process: A novel approach. International Journal of Environmental Research and Public Health, 14(10).
https://doi.org/10.3390/ijerph14101222

Xiong, Y., & Dai, L. (2023). Does green finance investment impact on sustainable development: Role of technological innovation and renewable energy. Renewable Energy, 214(May), 342-349.
https://doi.org/10.1016/j.renene.2023.06.002

Zaidi, S. A. H., Zafar, M. W., Shahbaz, M., & Hou, F. (2019). Dynamic linkages between globalization, financial development and carbon emissions: Evidence from Asia Pacific Economic Cooperation countries. Journal of Cleaner Production, 228, 533-543. https://doi.org/10.1016/j.jclepro.2019.04.210

Zhang, X., Shi, X., Khan, Y., Khan, M., Naz, S., Hassan, T., Wu, C., & Rahman, T. (2023). The Impact of Energy Intensity, Energy Productivity and Natural Resource Rents on Carbon Emissions in Morocco. Sustainability (Switzerland), 15(8).
https://doi.org/10.3390/su15086720

Zhang, Y. J. (2011). The impact of financial development on carbon emissions: An empirical analysis in China. Energy Policy, 39(4), 2197-2203.
https://doi.org/10.1016/j.enpol.2011.02.026

Zhou, H., & Xu, G. (2022). Research on the impact of green finance on China's regional ecological development based on system GMM model. Resources Policy, 75(November 2021), 102454.
https://doi.org/10.1016/j.resourpol.2021.102454

https://ourworldindata.org/energy#explore-data-on-energy

https://databank.worldbank.org/