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Navigating the Sustainable Development Trilemma: Trade, Renewable Energy, and Basic Services Across Global Economies

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Abstract

This study explores the complex relationships between trade openness, CO_2 emissions, renewable energy consumption, GDP growth, and access to basic services in different economic contexts — developed, developing, and emerging economies. Using the World Bank data from 2000 to 2022, the study employs correlation and regression analysis to understand how these factors interact and affect sustainability and economic performance. The results show significant regional differences. Developed economies, characterized by high trade-to-GDP ratios, have lower CO_2 emissions but experience negative effects on GDP growth due to trade dependence. In contrast, emerging economies, with the lowest trade-to-GDP ratios, show smaller reductions in CO_2 emissions from trade and more pronounced environmental impacts. Developing countries with moderate trade ratios show mixed results in terms of economic and environmental outcomes. Renewable energy consumption emerges as a critical factor, especially in developing and emerging economies. In developing countries, high renewable energy use is positively associated with GDP growth and mitigates the negative impact of trade on carbon emissions. Emerging economies benefit significantly from increased investment in renewable energy, although their consumption remains moderate. Access to basic services such as sanitation and drinking water varies widely across regions. Developed economies enjoy high access, which supports stable economic conditions, while developing economies struggle with low access, which negatively impacts both economic and environmental outcomes. Emerging economies fall in between, requiring substantial infrastructure upgrades to improve sustainability. Gross capital formation has a mixed impact, with limited direct influence on CO_2 emissions and GDP growth, but remains critical to overall development. The study highlights the need for developed economies to reduce trade dependence and foster domestic innovation, for emerging economies to prioritize renewable energy investments, and for developing economies to balance renewable energy investments with infrastructure development. These findings are essential for policymakers seeking to integrate economic growth with environmental sustainability.

Keywords
Trade Openness; CO_2 Emissions; Renewable Energy; Economic Development; Access to Basic Services

JEL: Q56; Q42; Q43; O13; F11.

Introduction

The challenge of balancing economic growth with environmental sustainability is becoming increasingly urgent as global temperatures rise and environmental degradation accelerates. As nations strive to advance economically, the need to integrate sustainable practices into development strategies becomes critical (Watts et al., 2021; Raihan & Tuspekova, 2022). The adoption of renewable energy sources is often highlighted as a key strategy for achieving this balance, as it provides a path to reduce carbon emissions while supporting economic growth (Bhattacharya et al., 2016; Saidi & Omri, 2020; Kumar, 2020). However, the impact of renewable energy on economic growth is complex and varies across regions and income levels (Kirikkaleli et al., 2022; Baz et al., 2021).

Studies have shown that while renewable energy consumption can positively affect economic output in many countries, the relationship is not universally positive (Shahbaz et al., 2020; Kirikkaleli et al., 2022). For example, Ahmed and Shimada (2019) found a significant long-run relationship between renewable energy consumption and economic growth in several emerging and developing regions, but noted the dependence on non-renewable energy sources in Latin America and the Caribbean. Moreover, the transition to renewable energy poses a dilemma for policymakers, who must navigate between promoting economic development and reducing environmental impacts (Bhuiyan et al., 2022). Furthermore, as highlighted by Niu et al. (2021), factors such as the use of renewable energy, ecological conservation, and low-carbon technologies play a critical role in achieving carbon neutrality and require region-specific strategies for effective implementation.

Access to basic services, such as sanitation and drinking water, also plays a critical role in sustainable development. Improved access can improve quality of life and economic productivity, although its direct impact on economic growth needs to be further explored (Zafar et al., 2020). The influence of trade, gross capital formation, and theoretical frameworks on sustainability add another layer of complexity to understanding the interplay between economic and environmental factors (Apergis & Payne, 2010; Murshed et al., 2021).

The study seeks to explore these dynamics by analysing the World Bank data from 2000 to 2022, focusing on how trade, CO_2 emissions, renewable energy consumption, GDP growth, capital formation, and access to basic sanitation and drinking water services influence sustainability in different economies. By synthesizing findings from different studies, this research aims to provide a comprehensive understanding of the factors that drive sustainable economic development.

Research Objective

The paper aims to examine the interplay between renewable energy consumption, trade, carbon emissions, and access to basic services, and their collective impact on sustainable economic development in different economic contexts.

To achieve this overall goal, the study has addressed the following specific research objectives:

1. To analyze the relationship between trade openness and CO_2 emissions in developed, developing, and emerging economies.
2. To examine the impact of renewable energy consumption on economic growth and CO_2 emissions.
3. Assess the role of access to basic services, such as sanitation and drinking water, in supporting economic growth and environmental sustainability.
4. Assess the impact of gross capital formation on economic growth and environmental sustainability.

Literature Review

Introduction to the Literature Review

The literature on the nexus between economic growth and environmental sustainability encompasses various theories and empirical studies that examine how economic activities affect the environment and how sustainable practices can be integrated into economic development strategies. This review synthesizes the findings of numerous studies, highlighting the relationships among economic growth, renewable energy consumption, access to basic services, trade, gross capital formation, and the theoretical frameworks relevant to understanding these dynamics. Recent research emphasizes the importance of regional and sectoral analysis, as demonstrated by studies examining China's economic and environmental dynamics (Yan et al., 2020; Chen et al., 2017; Niu et al., 2021; Steblyanskaya et al., 2022).

Economic Growth and Sustainability

Economic growth, traditionally measured by GDP, has often been associated with increased environmental degradation. However, recent studies show that integrating sustainability into economic policies can mitigate negative environmental impacts while maintaining economic progress. For example, the study by Fernandes et al. (2021) shows that sustainable technology transfer and innovation promote green growth, which has a positive impact on economic growth, suggesting a potential synergy between environmental sustainability and economic progress. Yan et al. (2020) add complexity to this discussion by emphasizing the importance of assessing not only GDP growth, but also economic efficiency and potential growth. Their study of China's provinces reveals disparities in economic performance, with Shandong showing superior results. This underscores the need for balanced regional development and addressing structural inefficiencies such as short supply chains and underutilized downstream industries.

Renewable Energy Consumption

Renewable energy consumption plays a key role in achieving environmental sustainability while supporting economic growth. The study by Bhattacharya et al. (2016) finds a significant positive impact of renewable energy on economic output in many countries, suggesting that increased investment in renewable energy can promote low-carbon growth. Similarly, Saidi and Omri (2020) find that renewable energy consumption not only drives economic growth but also reduces carbon emissions, demonstrating the dual benefits of renewable energy for sustainable development. Kirikkaleli et al. (2022) highlight regional differences, noting that while renewable energy consumption promotes sustainability, non-renewable sources still dominate energy use in Latin America and the Caribbean (Ahmed & Shimada, 2019). Niu et al. (2021) build on this by assessing provincial carbon neutrality capacity in China, identifying factors such as renewable energy use, ecological conservation, and low-carbon technologies as critical to achieving neutrality. Their findings call for tailored strategies to accelerate the transition to carbon neutrality across regions.

Access to Basic Services

Access to basic services such as sanitation and drinking water is critical to ensuring equitable development and improving quality of life. World Bank data show that improved access to these services can contribute to better health outcomes and higher economic productivity. While the literature does not comprehensively address the direct link between access to basic services and economic growth, it is clear that basic services are essential components of sustainable development. Chen et al. (2017) indirectly highlight this link by showing how capital investments in sectors such as construction and energy drive emissions. These findings suggest that improving infrastructure for basic services must be aligned with sustainable development goals to minimize environmental trade-offs.

Trade and Economic Development

Trade openness can affect economic growth and environmental sustainability in complex ways. Zafar et al. (2020) argue that education plays a critical role in moderating the positive effects of trade on environmental sustainability. Wang and Zhang (2021) find that trade openness generally reduces carbon emissions in high-income countries, but can increase emissions in low-income countries. This suggests that while trade can support economic development, it must be carefully managed to avoid increasing degradation of the environment. Steblyanskaya et al. (2022) add a regional disparities-related nuance by analyzing China's trade-related CO_2 emissions. They find that the Jiangsu province is acting as a major emitter without significant consumption of emission-intensive products, while Shandong province both emits and consumes high levels of CO_2-intensive goods, but has reduced emissions over time.

Gross Capital Formation

Gross capital formation, which includes investment in infrastructure, technology, and human capital, is essential for economic growth and development. The study by Apergis and Payne (2010) finds a long-run equilibrium relationship between capital formation and economic growth, underscoring the importance of investment in promoting economic progress. Baz et al. (2021) further point out that capital formation, when directed towards clean technologies, can contribute to environmental sustainability.

Theoretical Framework

Theoretical frameworks relevant to this study include sustainable development theory and ecological modernization theory. Sustainable Development Theory accentuates the need to balance economic growth with environmental protection and social equity (Steer & Wade-Gery, 1993). Ecological Modernization Theory suggests that technological innovation and changes in production processes can reconcile economic development with environmental sustainability (Weber & Weber, 2020). Yan et al. (2020) and Niu et al. (2021) extend these frameworks by integrating complexity theory and multi-indicator models, emphasizing the role of efficiency, equity, and tailored regional strategies in sustainable development.

Gaps in the Literature

The existing literature provides valuable insights into the linkages between economic growth, renewable energy consumption, and environmental sustainability. Yet, notable gaps still remain. For example, there is insufficient understanding of how renewable energy consumption affects economic growth across different regions (Bhattacharya et al., 2016; Saidi & Omri, 2020), suggesting that further research is needed to clarify the effects in low-, middle-, and high-income countries (Kirikkaleli et al., 2022). Similarly, the role of access to basic services in promoting sustainability remains underexplored, despite its importance for sustainable development (Zafar et al., 2020).

Cross-Country Comparative Analysis

This study uses data from the World Bank database covering the period 2000 to 2022 to conduct a comparative analysis of various countries based on key macroeconomic and environmental indicators. The selected indicators include trade (% of GDP), CO_2 emissions (kg per 2015 US$ GDP), renewable energy consumption (% of total final energy consumption), GDP growth (annual %), gross capital formation (% of GDP), and access to basic sanitation and drinking water services. These indicators provide a comprehensive view of economic performance and sustainability across countries.

Based on criteria derived from authoritative sources such as the World Bank, the International Monetary Fund (IMF), and the United Nations Development Program (UNDP), the countries in the study are divided into three categories: developing countries, developed countries, and emerging economies.

Developing countries in this study include Zambia, Tanzania, and Ghana. These countries were classified as developing based on the World Bank's 2022 classification of low-income or lower-middle-income economies. They are characterized by lower levels of industrialization, lower GDP per capita, and ongoing efforts to stabilize and grow their economies while facing various challenges related to economic development and environmental sustainability.

In contrast, the developed countries in this study, Canada, Sweden, and Germany-represent advanced economies with established infrastructure and higher levels of economic stability. They are classified by the World Bank as high-income economies, with strong human development indicators, advanced industrialization, and robust institutions. These countries' patterns of economic and environmental indicators are expected to be different from those of the developing countries.

Emerging markets such as South Africa, India and Indonesia were selected based on the IMF's Emerging Market and Developing Economies (EMDE) group and their inclusion in indices such as the MSCI Emerging Markets Index. These countries are characterized by rapid economic growth and industrialization, as well as significant structural transformation. However, they continue to face challenges in achieving sustainability and economic stability, which places them between developed and developing countries.

By examining the differences and similarities among these groups, the study aims to shed light on how different levels of economic development affect trade, environmental performance, capital formation, and access to basic services. The classification framework ensures a meaningful and systematic comparison that reflects differences in economic structures, institutional capacities, and sustainability challenges. The results will provide valuable insights for policy makers and contribute to a better understanding of the relationship between development status and economic and environmental outcomes.

Methodology

This study uses a cross-sectional comparative analysis to examine the interactions between renewable energy consumption, economic growth, environmental sustainability, and access to basic services in developed, developing, and emerging economies. Using the World Bank data from 2000 to 2022, the study aims to provide a nuanced understanding of how these variables influence sustainable development in different economic contexts.

Data for the analysis is drawn from the World Bank's database, which is known for its comprehensive and reliable economic and environmental indicators. The key variables include trade (% of GDP), CO_2 emissions (kg per 2015 US$ GDP), renewable energy consumption (% of total final energy consumption), GDP growth (% per year), gross capital formation (% of GDP), and access to basic sanitation and drinking water (%). These indicators capture the key aspects of economic openness, carbon intensity, renewable energy deployment, economic performance, investment levels, and access to essential services.

The countries in the study are grouped into three categories: developed economies (Canada, Sweden, and Germany), developing economies (Zambia, Tanzania, and Ghana), and emerging economies (South Africa, India, and Indonesia). This classification facilitates a comparative analysis of economic and environmental dynamics at different levels of development.

The methodology includes several key statistical techniques. Descriptive statistics are calculated to summarize the central tendencies and variations of each indicator within the different country groups. Pearson correlation coefficients are used to examine the relationships between variables, such as the effect of trade on CO_2 emissions and GDP growth. Linear regression models are used to find out how renewable energy consumption and other factors affect GDP growth and CO_2 emissions. Separate regression analyses are performed for each group of countries to identify variations in these relationships.

A moderation analysis is conducted to assess how the level of trade and gross fixed capital formation influence the effect of renewable energy consumption on CO_2 emissions. Interaction terms are included in the regression models to test these moderating effects and provide insight into how trade dependence and capital formation affect the relationship between renewable energy and emissions reductions.

Data analysis is performed using Jamovi, an open-source statistical software package that supports a range of analytical techniques. Jamovi is used for descriptive statistics, correlation analysis, and regression modelling; it provides user-friendly interfaces and robust statistical tools. This software enables comprehensive analysis and visualization of data, ensuring accurate and reliable results.

The methodology has certain limitations, including potential data availability issues and regional variability within countries that may not be fully captured in the analysis. While the study uses correlation and regression analysis to identify associations and trends, it does not establish causality.

Overall, the methodology provides a structured approach to understanding the dynamics of sustainable development, using Jamovi to perform statistical analysis and make cross-country comparisons. This approach aims to provide valuable insights into how economic growth, renewable energy consumption, and access to basic services interact in different economic contexts.

Results

Descriptive Statistics

The descriptive statistics presented in Table 1 provide valuable insights into the economic dynamics of developed, developing and emerging economies. Each economic typology is analyzed across several key variables, including trade (% of GDP), CO_2 emissions (kg per 2015 US$ GDP), renewable energy consumption (% of total final energy consumption), GDP growth (% per year), gross capital formation (% of GDP), and access to basic sanitation and drinking water services.

Table 1. Descriptive Statistics

	Economic Typologies	Trade (% of GDP)	CO_2 emissions (kg per 2015 US$ of GDP)	Renewable energy consumption (% of total final energy consumption)	GDP growth (annual %)	Gross capital formation (% of GDP)	People using at least basic sanitation services (% of population)	People using at least basic drinking water services (% of population)
N	Developed	69	69	69	69	69	69	69
	Developing	69	69	69	69	69	69	69
	Emerging economies	69	69	69	69	69	69	69
Mean	Developed	77.0	0.222	25.1	1.87	22.7	99.2	99.6
	Developing	62.6	0.216	72.3	5.71	24.2	21.6	60.0
	Emerging economies	49.0	0.915	26.2	4.44	26.9	59.7	87.2
Median	Developed	79.9	0.233	21.6	2.21	22.8	99.2	99.6
	Developing	64.9	0.224	83.8	5.80	27.0	22.5	59.8
	Emerging economies	49.3	1.04	30.6	5.01	29.7	63.9	87.9
Skewness	Developed	–0.0132	–0.0268	0.493	–1.24	0.157	0.707	–0.0103
	Developing	0.124	–1.46	–1.52	–0.148	–0.671	–0.159	–0.0917

Table 1. Continued

	Economic Typologies	Trade (% of GDP)	CO_2 emissions (kg per 2015 US$ of GDP)	Renewable energy consumption (% of total final energy consumption)	GDP growth (annual %)	Gross capital formation (% of GDP)	People using at least basic sanitation services (% of population)	People using at least basic drinking water services (% of population)
	Emerging economies	–0.171	–0.828	–0.223	–1.38	–0.122	–0.856	–0.538
Std. error skewness	Developed	0.289	0.289	0.289	0.289	0.289	0.289	0.289
	Developing	0.289	0.289	0.289	0.289	0.289	0.289	0.289
	Emerging economies	0.289	0.289	0.289	0.289	0.289	0.289	0.289
Kurtosis	Developed	–0.935	–1.23	–0.795	2.21	–0.290	0.549	–1.59
	Developing	–0.289	2.14	2.03	3.05	–0.497	–0.990	–0.698
	Emerging economies	0.181	0.114	–1.45	3.12	–1.31	0.109	–0.476
Std. error kurtosis	Developed	0.570	0.570	0.570	0.570	0.570	0.570	0.570
	Developing	0.570	0.570	0.570	0.570	0.570	0.570	0.570
	Emerging economies	0.570	0.570	0.570	0.570	0.570	0.570	0.570
	Developing	0.969	0.839	0.785	0.957	0.908	0.963	0.981
	Emerging economies	0.986	0.909	0.898	0.903	0.932	0.933	0.958
	Developing	0.089	< .001	< .001	0.019	< .001	0.040	0.393
	Emerging economies	0.634	< .001	< .001	< .001	0.001	0.001	0.022

Source: Jamovi Computation

Developed economies have a high mean trade-to-GDP ratio (77%) with a minimal skewness (–0.0132), indicating a relatively symmetric distribution around the mean. Developing economies have a lower mean (62.6%) but a positive skewness (0.124), indicating a concentration of countries with trade percentages below the mean. Emerging economies have the lowest mean (49%) and a slightly negative skewness (–0.171), indicating that some countries have significantly larger share of trade than the median (49.3%).

Developed and developing economies have similar mean CO_2 emissions (0.222 and 0.216, respectively), while emerging economies have much higher emissions

(0.915). Skewness values suggest a symmetric distribution for developed economies (–0.0268) and a negative skewness for both developing economies (–1.46) and emerging economies (–0.828), highlighting higher emissions in a few countries within these groups. The high kurtosis for developing countries (2.14) also suggests that emissions data are clustered around the mean.

Developing economies have the highest average renewable energy consumption (72.3%), while developed economies have the lowest (25.1%). Emerging economies fall in between (26.2%). The skewness for developing economies (–1.52) suggests that a few countries have exceptionally high renewable energy use, contributing to this figure, while the kurtosis (2.03) indicates a peaked distribution.

Developing economies have the highest average GDP growth (5.71%), the developed ones lag behind with an average of 1.87% and emerging economies fall in between at 4.44%. All typologies have negative skewness, particularly developed (–1.24) and emerging (–1.38), indicating that a few countries have experienced significantly higher GDP growth rates than the majority. The kurtosis for both developing countries (3.05) and emerging markets (3.12) shows that growth is concentrated around the mean with few extreme outliers.

Developed economies have a mean of 22.7%, while developing and emerging economies have slightly higher means (24.2% and 26.9%, respectively). Developing economies have a negative skewness (–0.671), indicating that most countries have values above the mean, while emerging economies have a minimal skewness (–0.122), reflecting a more balanced distribution.

Access to basic sanitation and drinking water is almost universal in developed economies, with averages of 99.2% and 99.6%, respectively. Access to basic sanitation (21.6%) and drinking water (60.0%) is significantly lower in developing countries. Emerging economies report intermediate values (59.7% and 87.2%). The skewness for developing countries (–0.159 for sanitation, –0.0917 for drinking water) reflects a distribution slightly skewed toward higher values, while emerging economies have a more negative skewness, indicating higher values for a minority of countries.

In a nutshell, developed economies generally show greater stability in their economic indicators, while developing and emerging economies show greater variability, particularly in renewable energy consumption, GDP growth, and access to basic services. These variations underscore the challenges and disparities that developing and emerging economies face in achieving sustainable economic growth and equitable access to resources.

Correlation Matrix of Variables across Countries

The correlation matrix in Table 2 provides insight into the relationships between key economic, environmental, and infrastructure variables across countries. Each correlation is analyzed using Pearson's r, with different levels of significance indicated by p-values.

Table 2. Correlation Matrix

		Trade (% of GDP)	CO_2 emissions (kg per 2015 US$ of GDP)	Renewable energy consumption (% of total final energy consumption)	GDP growth (annual %)	Gross capital formation (% of GDP)	People using at least basic sanitation services (% of population)	People using at least basic drinking water services (% of population)
Trade (% of GDP)	Pearson's r	—						
	df	—						
	p–value	—						
CO_2 emissions (kg per 2015 US$ of GDP)	Pearson's r	–0.434 ***	—					
	df	205	—					
	p–value	< .001	—					
Renewable energy consumption (% of total final energy consumption)	Pearson's r	–0.093	–0.342 ***	—				
	df	205	205	—				
	p–value	0.185	< .001	—				
GDP growth (annual %)	Pearson's r	–0.239 ***	–0.006	0.423 ***	—			
	df	205	205	205	—			
	p–value	< .001	0.932	< .001	—			

Table 2. Continued

		Trade (% of GDP)	CO_2 emissions (kg per 2015 US$ of GDP)	Renewable energy consumption (% of total final energy consumption)	GDP growth (annual %)	Gross capital formation (% of GDP)	People using at least basic sanitation services (% of population)	People using at least basic drinking water services (% of population)
Gross capital formation (% of GDP)	Pearson's r	–0.251 ***	0.041	0.094	0.111	—		
	df	205	205	205	205	—		
	p–value	< .001	0.559	0.176	0.113	—		
People using at least basic sanitation services (% of population)	Pearson's r	0.314 ***	–0.060	–0.702 ***	–0.571 ***	–0.084	—	
	df	205	205	205	205	205	—	
	p–value	< .001	0.393	< .001	< .001	0.227	—	
People using at least basic drinking water services (% of population)	Pearson's r	0.358 ***	0.151 *	–0.839 ***	–0.491 ***	–0.044	0.853 ***	—
	df	205	205	205	205	205	205	—
	p–value	< .001	0.030	< .001	< .001	0.532	< .001	—

Note. * p < .05, ** p < .01, *** p < .001. *Source*: Jamovi Computation

Trade is negatively correlated with CO_2 emissions ($r = -0.434$, $p < 0.001$), suggesting that countries with higher trade as a percentage of GDP tend to have lower CO_2 emissions per unit of GDP. Trade is also significantly negatively correlated with GDP growth ($r = -0.239$, $p < 0.001$) and gross capital formation ($r = -0.251$, $p < 0.001$), suggesting that higher trade shares may be associated with slower economic growth and lower capital formation. On the other hand, trade is positively correlated with access to basic sanitation ($r = 0.314$, $p < 0.001$) and basic drinking water ($r = 0.358$, $p < 0.001$), reflecting that countries with higher trade tend to have better access to basic services.

CO_2 emissions are negatively correlated with renewable energy consumption ($r = -0.342$, $p < 0.001$), meaning that countries with higher renewable energy consumption tend to have lower CO_2 emissions per unit of GDP. It is interesting that CO_2 emissions do not significantly correlate with GDP growth ($r = -0.006$, $p = 0.932$) or gross capital formation ($r = 0.041$, $p = 0.559$), suggesting that there is no clear relationship between emissions and these economic indicators. However, emissions are significantly and negatively correlated with access to basic drinking water services ($r = -0.151$, $p = 0.030$), suggesting that higher emissions are associated with poorer access to clean water.

Renewable energy consumption has a strong positive correlation with GDP growth ($r = 0.423$, $p < 0.001$), suggesting that countries that invest in renewable energy tend to experience higher economic growth. However, renewable energy is negatively correlated with access to basic sanitation ($r = -0.702$, $p < 0.001$) and basic drinking water ($r = -0.839$, $p < 0.001$), suggesting that countries with high renewable energy consumption may face challenges in providing basic services. This may reflect the lower level of development of countries that rely heavily on renewable energy sources.

GDP growth shows a strong negative correlation with access to basic sanitation ($r = -0.571$, $p < 0.001$) and drinking water ($r = -0.491$, $p < 0.001$). This suggests that higher economic growth does not always coincide with improved access to basic services, possibly highlighting inequality or uneven development in rapidly growing economies. In addition, GDP growth is positively correlated with renewable energy consumption ($r = 0.423$, $p < 0.001$), reinforcing the idea that countries that adopt renewable energy tend to experience stronger growth.

Gross capital formation does not show strong correlations with other variables, except for a slightly negative relationship with trade ($r = -0.251$, $p < 0.001$). This suggests that while capital formation is an important economic measure, it may not be directly related to environmental or infrastructure variables in this context.

Access to basic sanitation services is strongly negatively correlated with renewable energy consumption ($r = -0.702$, $p < 0.001$) and GDP growth ($r = -0.571$, $p < 0.001$), suggesting that countries that focus on economic expansion and renewable energy may lag behind in providing sanitation services. Similarly, access to basic drinking water services is negatively correlated with renewable energy consumption ($r = -0.839$,

$p < 0.001$) and GDP growth ($r = -0.491$, $p < 0.001$), but positively correlated with access to sanitation services ($r = 0.853$, $p < 0.001$), suggesting that these two services often improve together.

In summary, the correlation matrix shows significant relationships between trade, environmental sustainability, economic growth and access to basic services. Countries that trade more tend to have lower emissions and better access to basic services, while countries that focus on renewable energy and growth may face challenges in infrastructure development. These relationships underscore the complex interplay between economic progress, environmental sustainability and access to basic services.

Linear Regression Analysis of GDP Growth

The results of the linear regression model provide significant insights into the relationships between different predictors and GDP growth (annual %). The model from Table 3 shows a good overall fit, with an R^2 of 0.676, meaning that about 67.6% of the variance in GDP growth is explained by the predictors included in the model. The adjusted R^2 is slightly lower at 0.623, taking into account the number of predictors, and the F-test ($F = 12.8$, $p < 0.001$) confirms the overall significance of the model, indicating that the predictors together provide a statistically significant explanation for the variation in GDP growth.

Table 3. Model Fit Measures

				Overall Model Test			
Model	**R**	**R^2**	**Adjusted R^2**	**F**	**df1**	**df2**	**p**
1	0.822	0.676	0.623	12.8	29	177	< .001

Source: Jamovi Computation

The results of the omnibus ANOVA test in Table 4 show that renewable energy consumption ($F = 17.352$, $p < 0.001$), access to basic sanitation ($F = 7.968$, $p = 0.005$), and access to basic drinking water ($F = 6.545$, $p = 0.011$) are highly significant predictors of GDP growth. Trade (% of GDP) is also a significant predictor ($F = 6.771$, $p = 0.010$), while gross capital formation is not statistically significant ($F = 0.630$, $p = 0.429$), indicating that variations in capital formation do not have a significant impact on GDP growth in this model. In addition, the effect of years ($F = 8.148$, $p < 0.001$) is highly significant, reflecting time effects on GDP growth. However, economic typologies are not significant predictors ($F = 1.469$, $p = 0.233$), suggesting that there are no substantial differences in growth patterns across economic classifications.

Table 4. Omnibus ANOVA Test

	Sum of Squares	df	Mean Square	F	p
Trade (% of GDP)	23.34	1	23.34	6.771	0.010
Renewable energy consumption (% of total final energy consumption)	59.81	1	59.81	17.352	< .001
Gross capital formation (% of GDP)	2.17	1	2.17	0.630	0.429
People using at least basic sanitation services (% of population)	27.46	1	27.46	7.968	0.005
People using at least basic drinking water services (% of population)	22.56	1	22.56	6.545	0.011
Year	617.91	22	28.09	8.148	< .001
Economic Typologies	10.13	2	5.06	1.469	0.233
Residuals	610.13	177	3.45		

Note. Type 3 sum of squares. *Source*: Jamovi Computation

The model coefficients in Table 5 show several significant relationships with GDP growth. Trade, measured as a percentage of GDP, has a negative and significant relationship with GDP growth (estimate = –0.0301, p = 0.010). This suggests that as trade increases, GDP growth decreases slightly. The standardized estimate of –0.18561 suggests a moderate impact of trade on GDP growth.

In contrast, renewable energy consumption is positively and significantly related to GDP growth (estimate = 0.0506, p < 0.001). This strong relationship is further supported by a standardized estimate of 0.47883, which implies that countries with higher renewable energy consumption tend to experience faster GDP growth.

On the other hand, basic sanitation shows a significant negative relationship with GDP growth (estimate = –0.0428, p = 0.005). This suggests that countries with better access to basic sanitation services may experience slower economic growth. The standardized estimate of –0.47642 reflects a strong negative effect.

Conversely, basic drinking water services have a positive and significant effect on GDP growth (estimate = 0.0660, p = 0.011). The moderately strong standardized effect of 0.41449 indicates that improved access to drinking water services is associated with higher economic growth.

In terms of annual effects, 2020 stands out with a significant negative effect on GDP growth (estimate = –6.7387, p < 0.001), likely reflecting the impact of global events such as the COVID-19 pandemic. Conversely, 2010 (estimate = 2.2340, p = 0.015) and 2022 (estimate = 2.4682, p = 0.018) show significant positive effects, suggesting periods of economic recovery or growth.

Table 5. Model Coefficients — GDP growth (annual %)

Predictor	Estimate	SE	t	p	Stand. Estimate
Intercept [a]	0.7188	2.8906	0.2486	0.804	
Trade (% of GDP)	–0.0301	0.0116	–2.6022	0.010	–0.18561
Renewable energy consumption (% of total final energy consumption)	0.0506	0.0121	4.1655	< .001	0.47883
Gross capital formation (% of GDP)	–0.0140	0.0176	–0.7935	0.429	–0.04143
People using at least basic sanitation services (% of population)	–0.0428	0.0152	–2.8227	0.005	–0.47642
People using at least basic drinking water services (% of population)	0.0660	0.0258	2.5583	0.011	0.41449
Year:					
2001–2000	–0.6608	0.8755	–0.7548	0.451	–0.21844
2002–2000	–0.5389	0.8770	–0.6145	0.540	–0.17813
2003–2000	–0.0286	0.8802	–0.0325	0.974	–0.00947
2004–2000	1.0658	0.8804	1.2105	0.228	0.35228
2005–2000	1.1198	0.8835	1.2675	0.207	0.37013
2006–2000	1.6107	0.8881	1.8137	0.071	0.53240
2007–2000	1.2526	0.8906	1.4064	0.161	0.41402
2008–2000	0.1224	0.8951	0.1367	0.891	0.04045
2009–2000	–2.2157	0.9049	–2.4485	0.015	–0.73237
2010–2000	2.2340	0.9118	2.4501	0.015	0.73844
2011–2000	2.0933	0.9172	2.2823	0.024	0.69193
2012–2000	0.4733	0.9223	0.5132	0.608	0.15644
2013–2000	0.4298	0.9338	0.4603	0.646	0.14207
2014–2000	0.2336	0.9431	0.2477	0.805	0.07723
2015–2000	–0.1556	0.9504	–0.1637	0.870	–0.05144
2016–2000	–0.1300	0.9581	–0.1356	0.892	–0.04296
2017–2000	0.6022	0.9660	0.6234	0.534	0.19905
2018–2000	0.1303	0.9746	0.1337	0.894	0.04308
2019–2000	–0.6542	0.9828	–0.6657	0.506	–0.21624
2020–2000	–6.7387	0.9981	–6.7519	< .001	–2.22743
2021–2000	1.6206	0.9960	1.6271	0.105	0.53567
2022–2000	2.4682	1.0354	2.3839	0.018	0.81585
Economic Typologies:					
Developing – Developed	0.3302	1.3826	0.2388	0.812	0.10913
Emerging economies – Developed	0.8540	0.7339	1.1637	0.246	0.28228

[a] Represents reference level. *Source*: Jamovi Computation

Assumption Checks

Assumption checks indicate that multicollinearity is not a significant issue for most predictors, as the Variance Inflation Factor (VIF) values are below 5. However, access to basic sanitation services (VIF = 3.95) and drinking water services (VIF = 3.79) approach higher levels of multicollinearity, which could potentially affect the precision of the coefficient estimates. Regarding normality, the Q-Q plot suggests that the residuals are not drastically non-normal, implying that any deviations from normality are unlikely to severely impact the model's inferences.

Table 6. Collinearity Statistics

	VIF	Tolerance
Trade (% of GDP)	1.67	0.599
Renewable energy consumption (% of total final energy consumption)	2.69	0.372
Gross capital formation (% of GDP)	1.22	0.819
People using at least basic sanitation services (% of population)	3.95	0.253
People using at least basic drinking water services (% of population)	3.79	0.264
Year	1.03	0.970
Economic Typologies	2.59	0.387

Source: Jamovi Computation

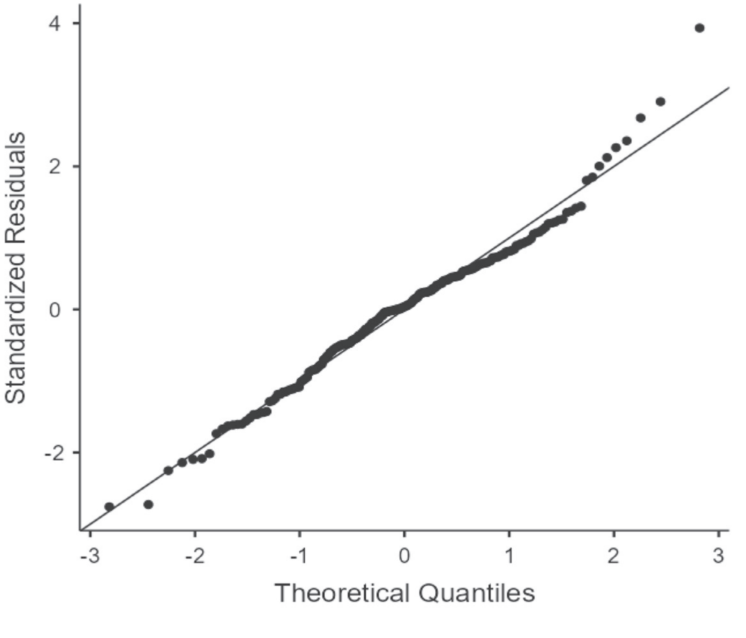

Figure 1. Q-Q Plot. *Source*: Jamovi Computation

In a nutshell, the linear regression model suggests that renewable energy consumption, trade, access to basic services, and certain years significantly influence GDP growth, while gross capital formation and economic typologies do not. The model provides valuable insights into the economic dynamics that influence growth, particularly the role of renewable energy and infrastructure development.

Linear Regression Analysis of CO_2 Emissions

The linear regression model in Table 7 shows a good fit, with an R value of 0.909, indicating a high correlation between the predictors and the dependent variable. The R^2 value of 0.826 indicates that approximately 82.6% of the variance in CO_2 emissions is explained by the model, while the adjusted R^2 of 0.797 confirms the robustness of the model given the number of predictors and the sample size. The overall model is statistically significant, as indicated by an F-statistic of 28.9 and a p-value of less than 0.001.

Table 7. Model Fit Measures

				Overall Model Test			
Model	**R**	**R^2**	**Adjusted R^2**	**F**	**df1**	**df2**	**P**
1	0.909	0.826	0.797	28.9	29	177	< .001

Source: Jamovi Computation

The results of the omnibus ANOVA test in Table 8 indicate that renewable energy consumption and access to basic sanitation are significant predictors of CO_2 emissions. Specifically, renewable energy consumption has a significant negative

Table 8. Omnibus ANOVA Test

	Sum of Squares	df	Mean Square	F	p
Renewable energy consumption (% of total final energy consumption)	1.3995	1	1.3995	40.87382	< .001
Trade (% of GDP)	5.02e-5	1	5.02e-5	0.00147	0.970
Gross capital formation (% of GDP)	0.0429	1	0.0429	1.25242	0.265
People using at least basic sanitation services (% of population)	0.5168	1	0.5168	15.09425	< .001
People using at least basic drinking water services (% of population)	0.1091	1	0.1091	3.18678	0.076
Year	4.5038	22	0.2047	5.97882	< .001
Economic Typologies	5.9090	2	2.9545	86.28607	< .001
Residuals	6.0606	177	0.0342		

Note. Type 3 sum of squares. *Source*: Jamovi Computation impact on CO_2 emissions with a p-value of less than 0.001. Similarly, access to basic sanitation is significantly associated with lower CO_2 emissions ($p < 0.001$). In contrast, trade and gross fixed capital formation have no significant effect on CO_2 emissions, with p-values of 0.970 and 0.265, respectively. Access to basic drinking water services has a marginal impact with a p-value of 0.076. Year and economic typology also have a significant impact on the model, with p-values less than 0.001.

The coefficients from the model in Table 9 indicate that higher renewable energy consumption is associated with a reduction in CO_2 emissions. The negative coefficient for renewable energy consumption (β=-0.00774) is statistically significant, reflecting its significant impact on reducing CO_2 emissions. The share of trade and gross fixed capital formation are not significant predictors, as indicated by their high p-values. Access to basic sanitation services also has a significant negative effect on CO_2 emissions, with a coefficient of β=-0.00587, while access to basic drinking water services has a marginal effect. The yearly coefficients vary, with significant negative effects observed in 2021 and 2022, indicating a decrease in CO_2 emissions in these years compared to the base year 2000. Economic typologies show that developing countries have a significant negative effect on CO_2 emissions compared to developed countries, while emerging economies have a significant positive effect.

Table 9. Model Coefficients — CO_2 emissions (kg per 2015 US$ of GDP)

Predictor	Estimate	SE	t	p	Stand. Estimate
Intercept[a]	1.50944	0.28810	5.2393	< .001	
Renewable energy consumption (% of total final energy consumption)	–0.00774	0.00121	–6.3933	< .001	–0.53926
Trade (% of GDP)	4.41e–5	0.00115	0.0383	0.970	0.00200
Gross capital formation (% of GDP)	–0.00197	0.00176	–1.1191	0.265	–0.04287
People using at least basic sanitation services (% of population)	–0.00587	0.00151	–3.8851	< .001	–0.48116
People using at least basic drinking water services (% of population)	–0.00459	0.00257	–1.7852	0.076	–0.21223
Year:					
2001–2000	0.01365	0.08726	0.1565	0.876	0.03323
2002–2000	0.01587	0.08741	0.1815	0.856	0.03862
2003–2000	0.02357	0.08773	0.2686	0.789	0.05735
2004–2000	0.02919	0.08775	0.3326	0.740	0.07103
2005–2000	0.02277	0.08805	0.2585	0.796	0.05540

Table 9. Continued

Predictor	Estimate	SE	t	p	Stand. Estimate
2006–2000	0.01928	0.08851	0.2178	0.828	0.04692
2007–2000	0.02185	0.08876	0.2462	0.806	0.05318
2008–2000	0.03254	0.08921	0.3648	0.716	0.07919
2009–2000	0.02977	0.09019	0.3300	0.742	0.07244
2010–2000	0.04376	0.09088	0.4815	0.631	0.10649
2011–2000	0.04009	0.09142	0.4385	0.662	0.09756
2012–2000	0.05480	0.09192	0.5961	0.552	0.13335
2013–2000	0.05291	0.09307	0.5685	0.570	0.12877
2014–2000	0.06050	0.09400	0.6437	0.521	0.14724
2015–2000	0.04574	0.09472	0.4829	0.630	0.11132
2016–2000	0.03755	0.09549	0.3932	0.695	0.09137
2017–2000	0.05032	0.09628	0.5227	0.602	0.12246
2018–2000	0.06001	0.09713	0.6178	0.538	0.14603
2019–2000	0.06676	0.09795	0.6816	0.496	0.16246
2020–2000	0.06498	0.09947	0.6532	0.514	0.15812
2021–2000	–0.38057	0.09927	–3.8339	< .001	–0.92615
2022–2000	–0.68718	0.10319	–6.6594	< .001	–1.67230
Economic Typologies:					
Developing – Developed	–0.27361	0.13780	–1.9856	0.049	–0.66585
Emerging economies – Developed	0.42207	0.07314	5.7704	< .001	1.02712

[a] Represents reference level. *Source*: Jamovi Computation

Assumption Checks

The collinearity statistics show that the Variance Inflation Factor (VIF) values are below 10 and the tolerance values are above 0.1, indicating that multicollinearity is not a major problem. The Shapiro-Wilk test indicates that the residuals are approximately normally distributed, with a statistic of 0.992 and a p-value of 0.369. Graphical checks, including the Q-Q plot and residuals plots, support the normality and homoscedasticity of the residuals, validating the regression model.

Table 10. Collinearity Statistics

	VIF	Tolerance
Renewable energy consumption (% of total final energy consumption)	2.69	0.372
Trade (% of GDP)	1.67	0.599
Gross capital formation (% of GDP)	1.22	0.819
People using at least basic sanitation services (% of population)	3.95	0.253
People using at least basic drinking water services (% of population)	3.79	0.264
Year	1.03	0.970
Economic Typologies	2.59	0.387

Source: Jamovi Computation

Table 11. Normality Test (Shapiro-Wilk)

Statistic	p
0.992	0.369

Source: Jamovi Computation

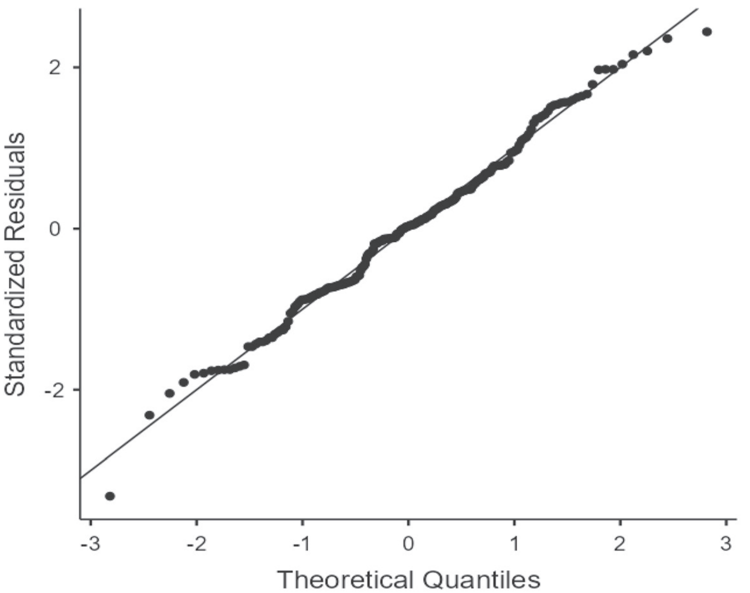

Figure 2. Q-Q Plot. *Source*: Jamovi Computation

Moderation Analysis

The Effect of Trade on the Relationship Between Renewable Energy Consumption and CO_2 Emissions

The moderation analysis examines the relationship between renewable energy consumption and trade (% of GDP) on the one hand and CO_2 emissions (kg per 2015 US$ GDP) on the other. The moderation estimates in Table 12 show that both renewable energy consumption and trade have significant negative effects on CO_2 emissions. Specifically, the estimate for renewable energy consumption is –0.00481 ($Z = -6.32$, $p < 0.001$), indicating that higher renewable energy consumption leads to lower CO_2 emissions. Similarly, the estimate for trade is –0.01224 ($Z = -10.66$, $p < 0.001$), suggesting that an increase in trade also reduces emissions.

The interaction effect between renewable energy consumption and trade is positive and significant ($p < 0.001$), indicating that the relationship between renewable energy consumption and CO_2 emissions depends on the level of trade. This positive interaction suggests that the negative impact of renewable energy consumption on emissions becomes weaker as trade increases.

Table 12. Moderation Estimates

	Estimate	SE	Z	p
Renewable energy consumption (% of total final energy consumption)	–0.00481	7.61e–4	–6.32	< .001
Trade (% of GDP)	–0.01224	0.00115	–10.66	< .001
Renewable energy consumption (% of total final energy consumption) ✻ Trade (% of GDP)	2.53e–4	4.00e–5	6.32	< .001

Source: Jamovi Computation

The simple slope analysis in Table 13 provides further insight into the impact of renewable energy consumption on emissions at different levels of trade. At the average level of trade, the effect of renewable energy consumption on emissions remains significantly negative ($\beta = -0.00481$, $p < 0.001$). At low levels of trade (one standard deviation below the mean), the negative effect is even stronger ($\beta = -0.00951$, $p < 0.001$), suggesting that in economies with less trade, renewable energy consumption has a greater impact on reducing emissions.

However, at high levels of trade (one standard deviation above the mean), the effect of renewable energy consumption on emissions becomes insignificant ($p = 0.935$). This suggests that in economies with high trade volumes, the impact of renewable energy consumption on emissions diminishes and is close to neutral.

Table 13. Simple Slope Estimates

	Estimate	SE	Z	p
Average	–0.00481	8.28e–4	–5.8036	< .001
Low (–1SD)	–0.00951	0.00105	–9.0859	< .001
High (+1SD)	–9.94e–5	0.00122	–0.0814	0.935

Note. This shows the effect of the predictor (Renewable energy consumption (% of total final energy consumption)) on the dependent variable (CO_2 emissions (kg per 2015 US$ of GDP)) at different levels of the moderator (Trade (% of GDP)). *Source*: Jamovi Computation

In a nutshell, the results indicate that renewable energy consumption significantly reduces CO_2 emissions but this effect is moderated by the level of trade. In economies with lower levels of trade, renewable energy consumption plays a more important role in reducing emissions, while in highly traded economies, the impact of renewable energy consumption is negligible. This interaction suggests that the benefits of renewable energy may be more pronounced in less trade-dependent economies, possibly due to differences in industrial activities, energy demand or trade-related emissions.

The Effect of Gross Capital Formation on the Relationship Between Renewable Energy Consumption and GDP Growth

Table 14 shows that renewable energy consumption has a positive effect on GDP growth with an estimate of 0.03740 and a highly significant $Z = 5.87$, $p < 0.001$, which means that increased consumption of renewable energy contributes to higher GDP growth. Gross capital formation (% of GDP) also has a significant positive effect on GDP growth ($\beta = 0.09379$, $Z = 4.64$, $p < 0.001$).

However, the interaction term between renewable energy consumption and gross fixed capital formation is significant and negative ($\beta = –0.00305$, $Z = –5.73$, $p < 0.001$). This indicates that the effect of renewable energy consumption on GDP growth is moderated by gross fixed capital formation that reduces the positive relationship between renewable energy consumption and GDP growth.

Table 14. Moderation Estimates

	Estimate	SE	Z	p
Renewable energy consumption (% of total final energy consumption)	0.03740	0.00637	5.87	< .001
Gross capital formation (% of GDP)	0.09379	0.02021	4.64	< .001
Renewable energy consumption (% of total final energy consumption) ✻ Gross capital formation (% of GDP)	–0.00305	5.32e–4	–5.73	< .001

Source: Jamovi Computation

The simple slope analysis in Table 15 provides further insight into how the effect of renewable energy consumption on GDP growth varies at different levels of gross capital formation. At the average level of gross capital formation, the effect of renewable energy consumption on GDP growth is positive and significant ($\beta = 0.0374$, $p < 0.001$).

When gross capital formation is low, the effect of renewable energy consumption on GDP growth is stronger ($\beta = 0.0646$, $p < 0.001$). This indicates that in contexts with lower levels of capital formation, renewable energy consumption has a more pronounced positive impact on GDP growth.

Conversely, at high levels of gross capital formation, the effect of renewable energy consumption on GDP growth diminishes ($\beta = 0.0102$, $p = 0.243$). This suggests that in contexts with higher levels of capital formation, the positive impact of renewable energy consumption on GDP growth is less pronounced and statistically insignificant.

Table 15. Simple Slope Estimates

	Estimate	SE	Z	p
Average	0.0374	0.00665	5.63	< .001
Low (–1SD)	0.0646	0.00782	8.27	< .001
High (+1SD)	0.0102	0.00872	1.17	0.243

Note. This shows the effect of the predictor (Renewable energy consumption (% of total final energy consumption)) on the dependent variable (GDP growth (annual %)) at different levels of the moderator (Gross capital formation (% of GDP)). *Source*: Jamovi Computation

The results indicate that renewable energy consumption has a positive impact on GDP growth, but this effect is moderated by gross capital formation. Specifically, while renewable energy consumption has a strong positive impact on GDP growth in environments with lower gross capital formation, this impact weakens and becomes less significant in environments with higher gross capital formation. This suggests that the benefits of renewable energy consumption for economic growth may be more pronounced when capital investment is lower.

The Effect of Gross Capital Formation on the Relationship Between Renewable Energy Consumption and CO_2 Emissions

Renewable energy consumption, as shown in Table 16, has a significant negative effect on CO_2 emissions with an estimate of –0.00482 ($Z = -5.128$, $p < 0.001$), indicating that higher renewable energy consumption leads to lower emissions. However, gross capital formation (% of GDP) has no significant direct effect on emissions ($\beta = 0.00145$, $p = 0.627$).

The interaction between renewable energy consumption and GFCF is not statistically significant ($p = 0.282$), meaning that GFCF does not significantly moderate the relationship between renewable energy consumption and CO_2 emissions.

Table 16. Moderation Estimates

	Estimate	SE	Z	p
Renewable energy consumption (% of total final energy consumption)	–0.00482	9.40e–4	–5.128	< .001
Gross capital formation (% of GDP)	0.00145	0.00298	0.487	0.627
Renewable energy consumption (% of total final energy consumption) ✻ Gross capital formation (% of GDP)	8.45e–5	7.85e–5	1.076	0.282

Source: Jamovi Computation

The simple slope analysis in Table 17 shows that the negative effect of renewable energy consumption on CO_2 emissions remains significant at different levels of gross capital formation. At average levels, renewable energy consumption significantly reduces emissions ($\beta = -0.00482$, $p < 0.001$). At low levels of GFCF this negative effect is slightly stronger ($\beta = -0.00558$, $p < 0.001$), while at high levels the effect is weaker but still significant ($\beta = -0.00407$, $p = 0.001$).

These results suggest that renewable energy consumption consistently reduces CO_2 emissions, regardless of the level of GFCF. However, the strength of this effect decreases slightly as GFCF increases.

Table 17. Simple Slope Estimates

	Estimate	SE	Z	p
Average	–0.00482	9.42e–4	–5.12	< .001
Low (–1SD)	–0.00558	0.00110	–5.05	< .001
High (+1SD)	–0.00407	0.00124	–3.27	0.001

Note. This shows the effect of the predictor (Renewable energy consumption (% of total final energy consumption)) on the dependent variable (CO_2 emissions (kg per 2015 US$ of GDP)) at different levels of the moderator (Gross capital formation (% of GDP)). *Source*: Jamovi Computation

The Effect of Trade on the Relationship Between Renewable Energy Consumption and GDP Growth

The moderation estimates in Table 18 show that renewable energy consumption (% of total final energy consumption) has a positive effect on GDP growth. The estimate is 0.0437 with a highly significant $Z = 6.65$, $p < 0.001$, meaning that an increase in renewable energy consumption is associated with higher GDP growth. In contrast, trade (% of GDP) has a negative effect on GDP growth with an estimate of –0.0354 ($Z = -3.56$, $p < 0.001$), indicating that higher levels of trade are associated with slower GDP growth.

However, the interaction term between renewable energy consumption and trade is not statistically significant (β = 3.63 × 10–4, p = 0.294), suggesting that the relationship between renewable energy consumption and GDP growth does not vary significantly with the level of trade.

Table 18. Moderation Estimates

	Estimate	SE	Z	p
Renewable energy consumption (% of total final energy consumption)	0.0437	0.00658	6.65	< .001
Trade (% of GDP)	–0.0354	0.00994	–3.56	< .001
Renewable energy consumption (% of total final energy consumption) ✻ Trade (% of GDP)	3.63e–4	3.46e–4	1.05	0.294

Source: Jamovi Computation

The simple slope in Table 19 also shows how the effect of renewable energy consumption on GDP growth changes at different levels of trade. At the average level of trade, the effect of renewable energy consumption on GDP growth remains positive and significant (β = 0.0437, p < 0.001). This effect holds for both low (–1 SD) and high (+1 SD) levels of trade. At low levels of trade, the effect is slightly smaller but still significant (β = 0.0370, p < 0.001), while at high levels of trade, the effect of renewable energy consumption on GDP growth is slightly stronger (β = 0.0505, p < 0.001).

Thus, regardless of the level of trade, renewable energy consumption has a positive impact on GDP growth, but the strength of this impact is not significantly moderated by trade.

Table 19. Simple Slope Estimates

	Estimate	SE	Z	p
Average	0.0437	0.00659	6.63	< .001
Low (–1SD)	0.0370	0.00838	4.41	< .001
High (+1SD)	0.0505	0.00999	5.06	< .001

Note. This shows the effect of the predictor (Renewable energy consumption (% of total final energy consumption)) on the dependent variable (GDP growth (annual %)) at different levels of the moderator (Trade (% of GDP)). *Source*: Jamovi Computation

Discussion

This study provides a comprehensive examination of how renewable energy consumption, economic growth, environmental sustainability, and access to basic services interact across developed, developing, and emerging economies. By analyzing descriptive statistics, correlation analysis, linear regression results, and moderation effects, we gain valuable insights into these dynamics.

Developed economies are characterized by high trade-to-GDP ratios, reflecting their deep integration into the global market. This high level of trade is associated with lower CO_2 emissions per unit of GDP, suggesting greater efficiency in managing emissions (Wang & Zhang, 2021). However, the negative correlation between trade and GDP growth suggests that economies that are highly dependent on trade may experience slower domestic growth. This could be due to overdependence on external markets, which may stifle domestic industrial development and innovation (Shahbaz et al., 2020). In contrast, developing countries have lower trade-to-GDP ratios and a positive skewness, indicating different levels of trade exposure, while emerging economies have even lower trade ratios and a negative skewness, reflecting different trade dynamics. While trade appears to help reduce CO_2 emissions, it may not directly support robust domestic GDP growth, especially if trade is concentrated in sectors with limited local value addition (Ahmed & Shimada, 2019).

Emerging economies have significantly higher CO_2 emissions than developed and developing economies, largely due to their industrial activities and energy consumption patterns (Bhattacharya et al., 2016). The negative correlation between CO_2 emissions and renewable energy consumption highlights the role of renewable energy in mitigating emissions. Countries that invest in renewable energy are likely to see a reduction in their carbon footprint (Saidi & Omri, 2020). In addition, the negative correlation between access to basic drinking water and CO_2 emissions suggests that poorer infrastructure may hinder effective environmental management. This finding implies that countries with higher emissions often struggle with inadequate infrastructure that exacerbates their environmental challenges (Zafar et al., 2021).

Developing countries lead in renewable energy consumption, which is positively correlated with GDP growth. This relationship highlights the role of renewable energy in driving economic expansion in these regions. However, the negative correlation between renewable energy consumption and access to basic services such as sanitation and drinking water suggests a trade-off in resource allocation. Developing economies may prioritize investments in renewable energy at the expense of infrastructure development, affecting overall service quality (Fernandes et al., 2021). In developed economies, where renewable energy consumption is lower, the focus may be on maintaining existing infrastructure rather than expanding renewable energy sources. Nevertheless, the positive relationship between renewable energy consumption and GDP growth in developing economies suggests that such investments are crucial for sustaining economic progress (Bhattacharya et al., 2016; Saidi & Omri, 2020).

Despite high GDP growth rates, developing countries often experience slower improvements in infrastructure, as evidenced by the negative correlations with access to sanitation and drinking water (Apergis & Payne, 2010). This suggests that rapid economic growth may not translate directly into improved basic services, potentially widening inequalities and delaying infrastructure improvements relative to economic expansion. In developed economies, high levels of access to basic services are associated with lower GDP growth rates. This may reflect a more mature economic environment in which infrastructure is already well developed, with a focus on optimizing existing systems rather than pursuing rapid growth (Murshed et al., 2021).

Gross capital formation shows weak correlations with environmental and infrastructure indicators, suggesting that while capital investment is critical for growth, it may not always be directed to areas that significantly impact environmental sustainability or access to basic services (Apergis & Payne, 2010). Effective capital allocation is critical to aligning growth with broader development goals. Access to basic sanitation and drinking water is nearly universal in developed economies, reflecting advanced infrastructure and high standards of living. Developing countries lag significantly behind in providing these basic services, while emerging economies fall between these extremes (Zafar et al., 2021). The negative correlation between access to basic services and renewable energy consumption suggests that countries that prioritize immediate infrastructure needs may have less capacity to invest in renewable technologies (Bhattacharya et al., 2016).

The moderation analysis shows that the effectiveness of renewable energy consumption in reducing CO_2 emissions is influenced by the level of trade. Specifically, at lower levels of trade, the reduction in CO_2 emissions due to renewable energy consumption is more pronounced ($\beta = -0.00951$, $p < 0.001$). However, as the level of trade increases, this effect diminishes, suggesting that highly trade-dependent economies may experience reduced benefits from renewable energy in terms of emission reductions. This interaction suggests that the environmental benefits of renewable energy are more pronounced in less trade-dependent economies (Wang & Zhang, 2021). Furthermore, the interaction between renewable energy consumption and gross capital formation shows a significant positive effect on GDP growth, highlighting that integrating renewable energy investments with increased capital formation can amplify growth (Shahbaz et al., 2020).

The Research Gaps Addressed by the Study

This study addresses several important gaps in the literature on the interplay between economic growth, environmental sustainability, and renewable energy consumption. An important gap that this research fills is the lack of detailed comparative analysis of the impact of trade openness on carbon emissions in different economic contexts. Previous studies have often generalized the impact of trade on the environment, suggesting that trade openness may reduce emissions in high-income countries but increase them in low-income countries (Wang & Zhang, 2021; Rahman et al., 2020). The present study provides a more nuanced examination by comparing trade-to-GDP ratios and CO_2 emissions across developed, developing, and emerging economies. This approach provides a clearer understanding of how trade openness affects environmental performance in different economic environments, filling a significant gap in region-specific insights.

Another important gap addressed by this study is the complex relationship between renewable energy consumption, economic growth, and CO_2 emissions. While previous research has found that renewable energy can positively impact both economic growth and emissions reduction (Bhattacharya et al., 2016; Saidi & Omri, 2020), there has been limited research on how these dynamics vary across different economic stages. This study provides a comprehensive analysis of how renewable energy consumption affects economic growth and CO_2 emissions in developed, developing, and emerging economies. It also examines the moderating effect of the level of trade on the relationship between renewable energy and emissions reductions, providing deeper insights into how renewable energy contributes to sustainability in different economic contexts.

The study also addresses the understudied impact of access to basic services, such as sanitation and drinking water, on economic and environmental outcomes. While improved access to these services is known to improve quality of life and productivity, its direct impact on economic growth and environmental sustainability has not been thoroughly examined across different economic stages (Zafar et al., 2021). This study examines how access to basic services affects GDP growth and CO_2 emissions, and finds that improved access to these services is positively associated with economic growth and reduced emissions. This finding addresses the gap in understanding the role of basic services in supporting sustainability in different economic environments.

Finally, the study examines the role of gross capital formation in economic and environmental outcomes, an area that has often been overlooked in previous research. While the importance of capital formation for economic growth is well documented (Apergis & Payne, 2010), its direct relationship to environmental indicators has received less attention. This study assesses the impact of gross capital formation on CO_2 emissions and other sustainability metrics, providing valuable insights into how investments in capital formation align with broader development goals and environmental outcomes. By addressing these gaps, the study contributes to understanding of how different factors interact to promote sustainable economic development.

Policy Implications

For developed economies, it is critical to develop strategies that balance trade dependence with domestic economic development. High trade openness can sometimes stifle domestic growth by shifting the focus away from domestic innovation and industry. To counter this, these economies should encourage innovation and diversify their domestic industries. This approach will help mitigate the negative effects of excessive trade dependence and promote sustainable domestic growth. By strengthening local industries and promoting technological advancement, developed countries can increase their economic resilience while maintaining a stable trade balance.

Emerging economies have much to gain by integrating renewable energy into their industrialization strategies. Not only does this help reduce CO_2 emissions, it also aligns with global environmental standards and promotes long-term sustainability. By prioritizing renewable energy investments, these countries can support their industrial growth and, at the same time, contribute to global environmental goals. Implementing policies that encourage the adoption of clean technologies and renewable resources will help emerging economies transition to more sustainable energy practices while achieving economic development.

Countries with high CO_2 emissions and inadequate infrastructure should prioritize investment in basic services such as water and sanitation. Improving infrastructure is essential for better environmental management and overall quality of life. Effective infrastructure development can alleviate some of the environmental pressures and result in better health outcomes, creating a stronger foundation for sustainable development. Investment in these critical areas is necessary not only for immediate improvements, but also for long-term environmental and economic stability.

The developing countries need to adopt a balanced approach where investments in renewable energy do not undermine essential infrastructure development. Integrated planning is a key to advancing both renewable energy and infrastructure. By ensuring that renewable energy initiatives are complemented by improvements in basic services, these economies can achieve a more equitable and sustainable development path. Such balance will help address immediate infrastructure needs while paving the way for long-term environmental benefits.

Policymakers must focus on directing capital investment to areas that support both economic growth and environmental sustainability. Effective capital allocation is critical to achieving inclusive development. Investments should be strategically planned to meet growth objectives taking into account their environmental impacts. By aligning capital investments with sustainability goals, policymakers can promote development that supports both economic progress and environmental protection, leading to more holistic progress.

Trade policies need to be aligned with environmental objectives to maximize the benefits of renewable energy. Countries should explore strategies that enhance the environmental impact of renewable energy, even in contexts of high trade dependency. By integrating environmental considerations into trade policy, countries can ensure that their trade activities contribute positively to sustainability goals. This alignment will help achieve the dual benefits of economic growth and environmental protection, making trade policy more effective in promoting long-term sustainability.

Recommendations

To address the complex relationships between trade, renewable energy consumption, economic growth and infrastructure development, several key recommendations are proposed to promote sustainability and inclusive growth in different economic contexts.

For developed economies, fostering domestic innovation and supporting industrial diversification are essential strategies to mitigate the negative effects of heavy trade dependence. By promoting innovation and expanding domestic industries, these economies can reduce their dependence on external markets and stimulate domestic economic growth. Supporting research and development and investing in new technologies will help maintain economic stability and enhance global competitiveness.

Emerging economies should prioritize investment in renewable energy infrastructure as part of their industrialization strategies. This will not only support industrial growth, but also help reduce carbon emissions. Developing a robust renewable energy infrastructure will enable these economies to meet global environmental standards while promoting long-term sustainability. Investment in clean energy technologies can drive both economic progress and environmental benefits, laying the foundation for future development.

Investment in basic services infrastructure, especially water and sanitation, should be a top priority. Improving infrastructure in these critical areas is essential for effective environmental management and improved living standards. Improved access to clean water and sanitation can have a significant impact on public health and economic productivity. By prioritizing these investments, countries can address immediate needs and build a stronger foundation for sustainable development.

Developing countries should aim to integrate renewable energy investments into overall infrastructure development. This approach ensures that progress in renewable energy does not come at the expense of essential services and infrastructure quality. Coordinated planning and investment in both renewable energy and infrastructure can lead to balanced progress that improves service delivery and supports sustainable growth.

Policymakers should focus on improving the efficiency of capital investment by strategically directing funds to areas that promote both economic growth and environmental sustainability. Effective capital allocation is critical to achieving inclusive development. By aligning capital investments with sustainability goals, policymakers can drive progress that supports long-term economic and environmental objectives.

Countries need to reassess their trade and environmental policies to ensure that renewable energy investments are optimized and environmental goals are met. This assessment is particularly important in trade-dependent contexts, where aligning trade practices with environmental objectives can maximize the benefits of renewable energy. Reassessing and updating policies to reflect both economic and environmental priorities will help achieve a more sustainable and balanced development path.

Table 20. The Study Summary

Variable	Developed Economies	Developing Economies	Emerging Economies	Key Correlations and Regression Results	Moderation Results	Policy Implications	Recommendations
Trade (% of GDP)	High trade-to-GDP ratio	Lower trade-to-GDP ratio	Lowest trade-to-GDP ratio	Trade is negatively correlated with CO_2 emissions and adversely impacts GDP growth.	The reduction in CO_2 emissions duetorenewable energy consumption is more pronounced at lower trade levels.	Developed economies should reduce dependency on external markets and foster domestic innovation. Developing economies should adopt diversified trade strategies to balance growth and sustainability.	Developed economies should focus on enhancing internal industries to lessen the impact of trade dependency. Developing economies should aim for balanced trade policies that support both local industries and environmental goals.
CO_2 Emissions (kg per 2015 US$ GDP)	Lower emissions	Moderate emissions	Higher emissions	CO_2 emissions are negatively correlated with renewable energy consumption and are reduced by renewable energy investments.	—	Emerging economies should focus on increasing renewable energy usage to mitigate high CO_2 emissions. Policies should encourage investments in renewable technologies and energy efficiency.	Emerging economies should prioritize renewable energy projects to lower emissions. All economies should promote policies that support renewable energy investments and energy-efficient practices.
Renewable Energy Consumption (%)	Lowest consumption	Highest consumption	Moderate consumption	Renewable energy is positively correlated with GDP growth and moderates the effect on CO_2 emissions by trade.	The combined effect of renewable energy and capital formation enhances GDP growth.	Developing economies should continue to invest in renewable energy. Developed economies should increase renewable energy investments to meet global sustainability goals and promote green growth.	All economies should integrate renewable energy investments with capital formation strategies to maximize economic and environmental benefits. Enhance support for renewable energy technologies and infrastructure.

Table 20. Continued

Variable	Developed Economies	Developing Economies	Emerging Economies	Key Correlations and Regression Results	Moderation Results	Policy Implications	Recommendations
GDP Growth (% per year)	Lower growth	Higher growth	Moderate growth	GDP growth is negatively correlated with sanitation access but positively correlated with renewable energy.	—	Developing and emerging economies need to enhance basic sanitation and drinking water access to support economic development. Developed economies should focus on optimizing existing infrastructure.	Improve basic sanitation and drinking water access in developing and emerging economies to boost economic performance. Developed economies should continue refining and optimizing infrastructure.
Gross Capital Formation (% of GDP)	Moderate formation	Moderate formation	Higher formation	Not significantly linked to CO_2 emissions or GDP growth.	—	Investments should be strategically directed to support both economic growth and environmental sustainability.	Ensure that capital investments are aligned with sustainability goals and address both economic and environmental priorities.
Basic Sanitation Access (%)	High access	Low access	Intermediate access	Basic sanitation access negatively affects GDP growth but reduces CO_2 emissions.	—	Focus on improving basic sanitation access in developing economies to bolster economic and environmental outcomes.	Prioritize infrastructure projects that enhance sanitation access in developing economies. Ensure continued investment in sanitation infrastructure.
Basic Drinking Water Access (%)	Universal access	Moderate access	High access	Positive impact on GDP growth.	—	Enhance access to basic drinking water to support economic growth, particularly in developing and emerging economies.	Expand access to clean drinking water in developing and emerging economies. Support infrastructure development to improve water access.

Source: Author (2024)

Conclusion

This study provides a comprehensive analysis of the complex interplay between trade, renewable energy consumption, economic growth, and environmental sustainability in developed, developing, and emerging economies. By examining World Bank data from 2000 to 2022, the study highlights how different economic contexts influence the dynamics between these critical variables. The results show that while renewable energy consumption positively impacts economic growth and helps reduce CO_2 emissions, its effectiveness varies significantly across regions. Developed economies, with their high trade exposure and stable infrastructure, show the patterns different from those of the developing and emerging economies, where investments in renewable energy often involve trade-offs with basic services provision and infrastructure development.

The study also highlights the critical role of access to basic services, such as sanitation and drinking water, in supporting economic growth and environmental sustainability. Improved access to these services is associated with better health outcomes and higher productivity, although it often competes with investments in renewable energy and infrastructure. Gross capital formation, being essential for economic development, has a complex relationship with sustainability outcomes, highlighting the need for effective capital allocation strategies.

The results show that trade openness affects CO_2 emissions and economic growth differently across income levels. While trade can reduce emissions in high-income economies, it may not have the same effect in low-income countries, where it sometimes leads to slower domestic growth. This nuanced understanding should help bridge the gap between economic development and environmental protection.

Overall, the study's insights into these relationships may provide guidance for policymakers seeking to balance economic growth with environmental sustainability. By understanding the specific dynamics at play in different economic contexts, policymakers can design more targeted strategies to promote sustainable development, improve basic services, and optimize investments in renewable energy.

Limitations of the Study

The comprehensive nature of this paper determines some of its limitations. First, the study relies on secondary data from the World Bank, which may not capture all the nuances of regional differences and local contexts. Data quality and availability can vary across countries, potentially affecting the accuracy and comparability of results.

Second, the study focuses on a specific time period, from 2000 to 2022, and thus may not take into account more recent developments in renewable energy technologies, policy changes, or economic shifts. This temporal limitation may affect the relevance of the findings in rapidly evolving contexts.

Besides, it does not delve deeply into the qualitative aspects of how trade policies, renewable energy investments, and infrastructure developments are implemented and their specific local impacts. Understanding these qualitative factors could provide a more nuanced perspective on the observed relationships.

Recommended Future Studies

To improve understanding of the interplay between economic growth and environmental sustainability, future research should focus on several key areas. First, expanding data sources beyond those provided by the World Bank could result in more nuanced insights. Incorporating data from national and regional databases would enable more detailed analysis, capturing variations in economic and environmental indicators that are not always apparent in global datasets. This broader data scope would help overcome any limitations related to data quality and availability, and improve the accuracy and comparability of results across regions.

Second, extending the study period to include more recent data is essential. As renewable energy technologies and economic conditions evolve rapidly, including data beyond 2022 would provide a more up-to-date perspective on these dynamics. This extension would help capture the latest trends and technological advances in renewable energy and their impact on economic and environmental outcomes, ensuring that the findings remain relevant and applicable in today's context.

Next, conducting qualitative research to explore the specific policies and implementation strategies related to trade, renewable energy investment, and infrastructure development would provide deeper insights. Understanding how these policies are designed and implemented at the local level can reveal important contextual factors that influence their effectiveness. Qualitative studies could uncover the mechanisms behind observed trends and provide a more comprehensive view of the impact of these policies on economic and environmental outcomes.

Finally, regional comparative studies within countries could provide valuable information on local challenges and opportunities. Examining the impact of renewable energy and access to basic services in specific regions would help identify regional disparities and tailor policies to local needs. This approach would allow for more targeted and effective policy recommendations, improving the overall balance between economic growth and environmental sustainability.

By addressing these areas, future research can build on the findings of this study to provide more comprehensive and actionable insights. This will contribute to bridging the gap between economic growth and environmental sustainability, ultimately supporting more effective policy and practice in different economic contexts.

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