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EDITORIAL

We feel honoured and privileged to present the Bi-Annual Peer Reviewed Refereed Journal, ISSN (Online): 2583-5203, Volume 4, No. 01, June, 2025 among our esteemed readers and academic fraternity.

This Journal is the outcome of the contributions of insightful research-oriented papers/articles by various eminent academicians, and research scholars in a highly organized and lucid manner with a clear and detailed analysis related to the emerging areas in the fields of Social Sciences and Allied Areas.

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We also express our sincere thanks and gratitude to all the contributors to research papers/ articles who have taken pain in preparing manuscripts, incorporating reviewer(s) valuable suggestions and cooperating with uxs in every possible way.

We also express our heartfelt gratitude to all the esteemed members of the Editorial Board, Esteemed Reviewer(s) who despite their busy schedules have given their valuable time, suggestions and comments to enrich the quality of the contributory resears paper(s) in bringing to light this June issue.

Last, but not least, we revere the patronage and moral support extended by our parents and family members whose constant encouragement and cooperation made it possible for us to complete on time.

We would highly appreciate and look forward to your valuable suggestions, comments and feedback at **editorbr2022@gmail.com**

June, 2025
West Bengal, India

PEMA LAMA
Editor-in-Chief

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RESEARCH ARTICLE

Exploring the Relationship between Economic Development and Renewable Energy: An Empirical Study of the World's Top 10 Economies

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ABSTRACT

Renewable energy investment has experienced unprecedented growth globally, reflecting a massive shift towards clean and green energy solutions, which makes a transition away from fossil fuels. Over the past decade, financial flows into renewable energy technologies such as solar, wind, hydro, and geothermal have surged, driven by favourable policy frameworks, technological advancements, and growing environmental awareness. In 2023, global investment in renewable energy reached a record high of approximately $500 billion, with significant contributions from both public and private sectors. The study is conducted among the world's top 10 richest nations to explore the relationship between economic size (measured in terms of GDP) and deployment of renewable energy. While earlier studies reveal that countries with higher GDPs intend greater investment towards renewable energy generation and the intensity of renewable energy generation (as measured in terawatt-hours per trillion USD of GDP) has remained unstudied.

This research paper applies correlation and regression analysis to examine the relationship between GDP and (1) total renewable energy generation and (2) Intensity of renewable energy. The study reveals a significant and positive correlation between GDP and renewable energy generation, ensuring that economic size plays a crucial role in scaling clean and green infrastructure. However, the relationship between economic size (GDP) and intensity of renewable energy reflects an inverse relationship, highlighting some discrepancies in efficiency. This paper provides insight for sustainable development through balanced economic growth and environmental performance.

1 INTRODUCTION

Climate change is one of the most concerning issues among all the issues that we are dealing with in the present scenario. Climate change can be termed as a long-term shift in global weather conditions mainly caused by human-based activities. This shift in the temperature and weather patterns has an adverse effect on the ecosystems, economies, and societies around the world. Climate change and environmental degradation have become a serious global concern, the shift from traditional energy towards renewable energy has become more crucial than ever. According to World Health Organization (WHO), almost 7 million people lost their life around the world due to air pollution. In today's world a major portion of air pollution comes from the manufacturing sector and from the power sector. With the development of the humanity and society, we are also developing negative impact to the environment in the form of pollutants which contributes to climate change and global warming. Thermal power stations generate electricity by converting heat energy into electric power which is done mainly through burning fossil fuel. In this process thermal power plants releases a lot of harmful gases to the atmosphere in the form of carbon dioxide, Green House Gas (GHG), Nitrogen Oxide (NOx), Sulfur Oxide (Sox) and Particulate Matters (PM).Green House Gas (GHG) is a type of gas which absorbs infrared radiation released from surface of the earth. By adopting renewable sources of energy, we can overcome serious issues like Carbon emission, climate change, global warming, Green House Gas (GHG) emission, sea level rise, flood etc. Energy produced from renewable sources produce very little to no emission, unlike energy produced from fossil fuels are the main contributors behind global issues like climate change and global warming.

Economic power (GDP) plays a crucial role in adopting renewable energy. The nations with higher financial resources and technology can implement large scale of renewable energy projects. However, nations with higher economic size are presume to implement higher generation of renewable energy but this assumption does not fully consider national policy framework, energy strategies and demand for energy. More importantly, the focus of this paper on intensity of renewable energy generation as measured in per trillion dollars of GDP, adds a new dimension to this analysis. This implies that how efficiently a country can converts its economic power (GDP) into renewable energy generation per GDP. Although several studies have been conducted on relationship between GDP and renewable energy generation but very few studies have been conducted on this relationship in context to top 10 richest nations around the globe. Moreover, very few studies have been conducted on the efficiency or intensity of renewable energy generation which shows how efficiently economic income of a country is associated towards clean and green energy performance. This paper studies the total renewable energy generation and Intensity of renewable energy generation in relation to economic size (GDP) and for this study the data has been collected for top 10 richest countries in world.

2 LITERATURE REVIEW

The study of relationship between Economic size and renewable energy generation plays an important role in sustainable development. Sadorsky (2009) and Apergis & Payne (2010) are among the earliest to study the relationship between economic growth and utilization renewable energy for OCED nations. The study established a positive correlation between the two variables, implying that as a nation's GDP increases, its investment towards clean energy also increases. The study conducted by Bhattacharya, Paramati, Ozturk, and Bhattacharya (2016) on 38 developing and developed nations has confirmed that renewable energy consumption is influenced by economic and financial development. The authors also stressed the support of institutional policy and quality. Ignat et al. (2018) in their study analyse 25 European countries, which suggests that strong economic strategies, policy framework and higher access to financial resources support the relationship between higher GDP and higher renewable energy generation. Wang, Wang, and Li (2020) reveals that the relation od GDP with renewable energy varies depending upon its source and region. The different sources of renewable energy, like solar, wind and hydropower, respond differently to the economic incentives and therefore suggest framing the policies accordingly.

Adebayo et al. (2022) state that the wealthiest nations have more advanced renewable energy generation infrastructure, but the efficiency or intensity of renewable energy generation is not optimal, as the demand for energy is higher, especially from the transport and industry sectors. Zhang & Yu (2023) analyse 90 countries in the Belt and Road Initiative through the Granger Causality test, which reveals that there is a positive relationship between Economic size (GDP) and renewable energy generation. The study on BRIC-T nations suggests that nations with lower economic income or power sometimes tend to show greater efficiency or intensity of renewable energy generation, which mainly happens due to their major dependence on hydro and bioenergy sources (Yıldırım & Dur, 2023). As the economic income (GDP) of a nation increases, at the preliminary stage of development, the utilisation of Traditional sources of energy (fossil fuel) tends to increase before shifting towards renewable sources. The study also reveals that there is a non-linear relationship between economic size (GDP) and renewable energy (Afrane et al.,2023). Zhang et al. (2023) in their study found that the countries with higher economic income tend to make investments towards renewable energy, which in turn results in economic progress.

3 RESEARCH GAP

Although several studies have been conducted on the growing literature of GDP and its relationship with renewable energy, either on the basis of consumption or generation but specifically the intensity or efficiency of renewable energy per GDP has remained underexplored. Moreover, very few studies have been conducted comparing the richest nations. This paper helps to bridge the gap by uniquely combining GDP, total renewable energy generation and intensity of renewable energy per GDP in the context of the world's top 10 richest nations.

4 OBJECTIVES OF THE STUDY

This study implements a quantitative correlational research design to explore the relationship between national economic size (measured by GDP) and renewable energy generation, as well as the intensity of renewable energy use among the top 10 richest nations.

- To determine the relationship between the economic size of a nation (GDP) with its total renewable energy generation.
- To evaluate whether there is any kind of association between economic size (GDP) and renewable energy intensity (TWh per trillion USD GDP).
- To study whether higher GDP resembles higher Intensity of renewable energy.

5 RESEARCH METHODOLOGY

The study is primarily focused on renewable sources of energy, which are the only alternative solutions to tackle climate change and its impact on the environment. To achieve the goal of this paper, mainly secondary data were gathered for the year 2023 from various economic and energy reports of Ministry of Renewable Energy, Ministry of Power, International Renewable Energy Agency (IRENA), Energy Institute Statistical Review of World Energy, etc. as well as from various journals, newspapers, articles and websites. The top 10 economies of the world have been selected and ranked according to their GDP for the study. The names of the countries are the USA, China, Germany, Japan, India, the United Kingdom, France, Brazil, Italy and Canada.

The following table describes the variable and type of data used to conduct the study

Variable Data	Type of Data	Explanation
GDP (USD Trillion)	Independent Data	National Economic Size
Total Renewable Energy Generation (TWh)	Dependent Data	Total Renewable Energy produced by a Nation
Intensity of Renewable Energy (TWh per million USD GDP)	Dependent Data	Renewable Energy produced per unit of GDP. It is an Efficiency Indicator

The data had been summarised employing descriptive statistics, and inferential statistics were conducted using Pearson Correlation Coefficient, Linear Regression analysis and Scatter Plots. For implementing the statistical tools and techniques, IBM SPSS software has been used.

6 DATA ANALYSIS AND FINDINGS

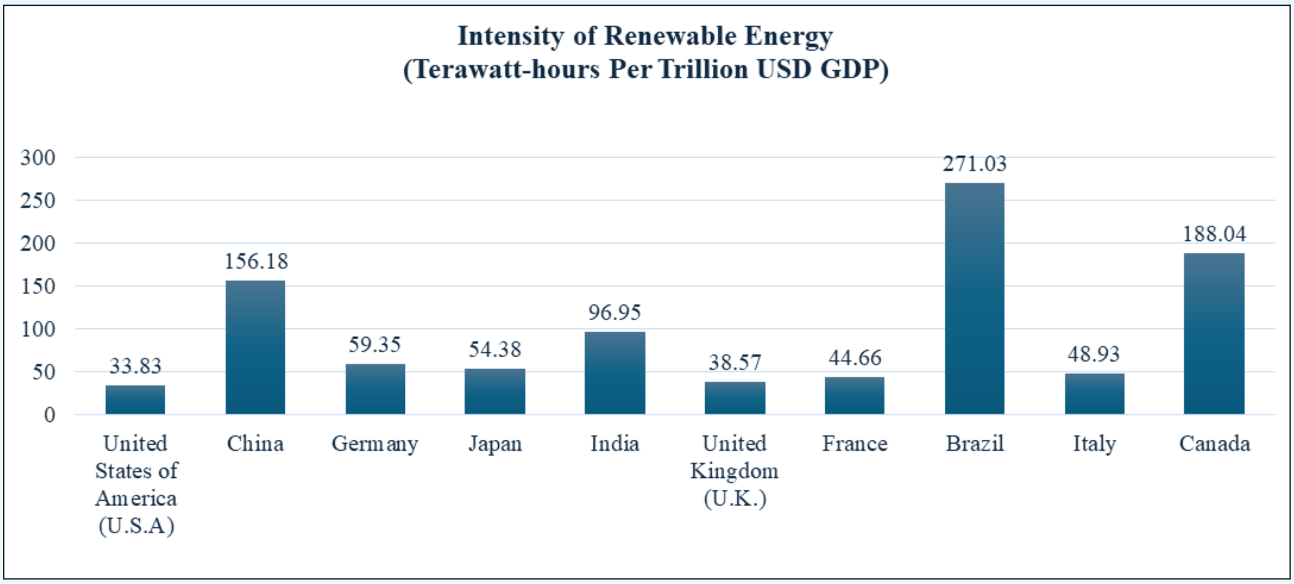
The top 10 richest countries in the world have been selected on the basis of their GDP (Gross Domestic Product). GDP refers to the monetary measurement of the market value of all the final goods and services produced or rendered by a country over a specific period. In the list of wealthiest nations USA stands on top with USD 28.78 trillion, followed by China with USD 18.53 trillion to secure the second richest country in the world, while Germany, Japan and India faces close competition among themselves with USD 4.59 trillion, USD 4.11 trillion and USD 3.94 trillion of GDP to stand on third, Fourth and fifth position respectively. United Kingdom, France, Brazil, Italy and Canada, with GDPs of USD 3.5 trillion, 3.13 trillion, 2.33 trillion, 2.44 secure 6th, 7th, 8th, 9th and 10th position.

Rank & Country	GDP (USD)	Total Renewable Energy Generation (Terawatt-hours)	Intensity of Renewable Energy (Terawatt-hours Per Trillion USD GDP)
United States of America (U.S.A)	$28.78 trillion	973.7	33.83
China	$18.53 trillion	2894.1	156.18
Germany	$4.59 trillion	272.4	59.35
Japan	$4.11 trillion	223.5	54.38
India	$3.94 trillion	382	96.95
United Kingdom (U.K.)	$3.5 trillion	135	38.57
France	$3.13 trillion	139.8	44.66
Brazil	$2.33 trillion	631.5	271.03
Italy	$2.33 trillion	114	48.93
Canada	$2.24 trillion	421.2	188.04

Source: https://www.forbesindia.com/article/explainers/top-10-largest-economies-in-the-world/86159/1

Source: https://www.statista.com/statistics/267233/renewable-energy-capacity-worldwide-by-country/

The graph below tries to demonstrate the renewable energy intensity of a nation. Renewable energy intensity is the ratio of renewable energy produced by a nation to and GDP. From the above bar diagram, we can clearly state that the renewable energy intensity of Brazil stood at the top with 271.03, despite Brazil being the seventh richest economy. In this list, Canada and China have secured 2nd and 3rd position with 188.04 and 156.18 TWh per Trillion USD, respectively, by demonstrating strong renewable sector investment in their economies. India as a nation has come up with a well-balanced economy with 96.95 TWh per Trillion USD, followed by Germany, Japan and Italy with 59.35, 54.38 & 48.93 TWh per Trillion USD. The renewable energy generation per GDP is relatively lower for the USA and the UK, despite being large economies, which indicates improvement in energy sustainability.



The hypothesis statement has been framed to examine the relationship between GDP and Total Renewable energy generation:

H_0: There is no correlation between GDP and total renewable energy generation.

H_1: There is a positive correlation between GDP and total renewable energy generation.

To examine the association between GDP and total renewable energy generation, specifically, whether total renewable energy generation of a nation changes with the change in GDP of that nation, Pearson correlation coefficient, Linear Regression, ANOVA test analysis and a scatter plot for Visualisation.

Pearson Correlation Coefficient

Pearson Correlation Coefficient (r) is a statistical tool used to measure the relationship between two continuous variables. The value of the correlation coefficient (r) ranges from -1 to +1. r>0, implies that if one variable trends to increase, then the other variable also increases and if r<0, then as one variable increases then the other variable decreases. r = 0 implies there is no relationship between the two variables. The formula for the Pearson correlation coefficient is:

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2} \cdot \sqrt{\sum(y_i - \bar{y})^2}}$$

Table 1
PEARSON CORRELATION BETWEEN GDP (USD) AND TOTAL RENEWABLE ENERGY GENERATION (TERAWATT-HOURS)

Correlations

		GDP (USD)	Total Renewable Energy Generation (Terawatt-hours)
GDP (USD)	Pearson Correlation	1	.639*
	Sig. (2-tailed)		.047
	N	10	10
Total Renewable Energy Generation (Terawatt-hours)	Pearson Correlation	.639*	1
	Sig. (2-tailed)	.047	
	N	10	10

*. Correlation is significant at the 0.05 level (2-tailed).

Table 1 shows the Pearson correlation between GDP (USD) and Total Renewable Energy Generation (Terawatt-hours). The Pearson correlation coefficient has come out as 0.639, which means there is a moderate to strong positive correlation between GDP and Total Renewable Energy Generation. This further implies that as GDP increases, the generation of renewable energy also tends to increase.

Regression Analysis

Table 2
VARIABLES ENTERED / REMOVED

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	GDP (USD)[b]	.	Enter

a. Dependent Variable: Total Renewable Energy Generation (Terawatt-hours)

b. All requested variables entered.

Table 2 provides information about the variables used in a regression analysis. GDP (trillion USD) as the independent (predictor) variable, and the dependent variable is Total Renewable Energy Generation (Terawatt-hours). No variables were removed from the model. The method used is Enter, which means the predictor variable (GDP) was entered into the regression model all at once (not stepwise or gradually).

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.639[a]	.408	.334	687.5533

a. Predictors: (Constant), GDP (USD)

Table 3
ANOVA

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2610970.591	1	2610970.591	5.523	.047[b]
	Residual	3781836.265	8	472729.533		
	Total	6392806.856	9			

a. Dependent Variable: Total Renewable Energy Generation (Terawatt-hours)

b. Predictors: (Constant), GDP (USD)

The ANOVA test (analysis of variance) provided in Table 4 states that regression is the variation in the independent variable, and residual is the variation left unexplained. The sum of Squares refers to the measure of variation in data. Sum of Squares for Regression (SSR) is 26,10,970.591 and Sum of Squares for Residual (SSE) is 37,81,836.265 as explained by the model. Total Sum of Square (SST) = SSR + SSE = 26, 10,970.591 + 37,81,836.265 = 63,92,806.856.

The degree of Freedom (df) is divided into 3 parts, while predicting a dependent variable (Y) with a single independent variable (X).

- Regression degree of freedom (df1) = k = 1.

Where, k = number of predictor values = 1 predictor i.e. GDP.

- Residual Error degree of freedom (df2) = n - k - 1 = 10 - 1 - 1 = 8

Where, n = number of observations,-1 is for intercept. Total degree of freedom (df3) = n - 1 = 10 - 1 = 9.

- Mean Square is calculated by dividing the Sum of Squares by its corresponding degree of freedom (df). Mean square for Regression and Residual is 26,10,970.591 and 4,72,729.533, respectively.

- F-statistics

$$FF - \frac{MS_{\text{R egression}}}{MS_{\text{Residual}}}$$

$$= \frac{26,10,970.591}{4,72,729.533} = 5.523$$

- Statistical Significance (p value) = 0.047

This regression model suggests a moderate, statistically significant positive relationship between GDP and renewable energy generation. The GDP variable explains about 40.8% of the variance in renewable energy output (from $R^2 = 0.408$), which is decent for a single-variable model.

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	177.187	287.350		.617	.555
	GDP (USD)	60.089	25.568	.639	2.350	.047

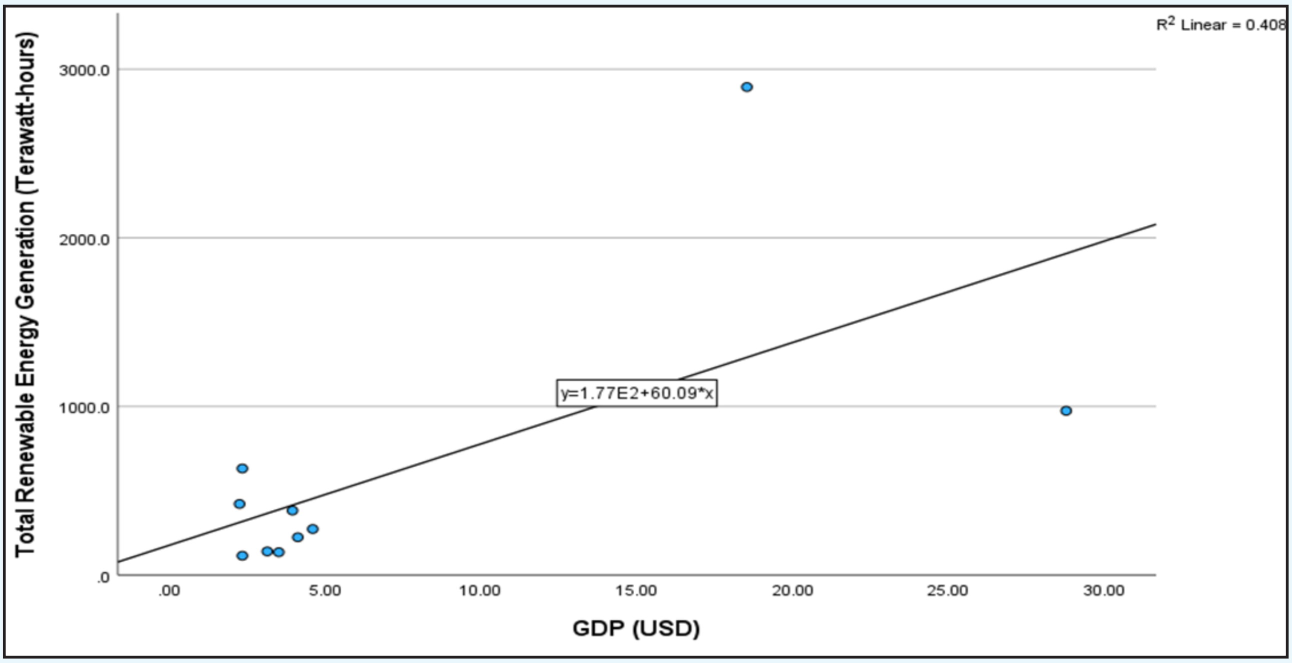
a. Dependent Variable: Total Renewable Energy Generation (Terawatt-hours)

- *Unstandardized Coefficients (B) are the values used in the actual Regression Equation:* Intercept (Constant) is the predicted value of renewable energy generation (177.187), when GDP is zero. While this is not realistic (as no country has exactly $0 GDP), it is part of the mathematical model and serves as the baseline. For each additional unit of GDP (in trillions of USD), renewable energy generation is predicted to increase by 60.089 TWh.

- *Standard Error:* Intercept SE = 287.350; GDP SE = 25.568 these values show the average amount that the coefficients vary from the true population value. Smaller SEs mean more precise estimates. Here, the GDP coefficient is relatively more stable than the constant.
- *Standardised Coefficient (Beta = 0.639):* This tells you the strength of the relationship in standardised units, making it easier to compare with other predictors if there were more variables. A beta of 0.639 shows a moderately strong positive relationship between GDP and renewable energy generation.
- *t-value and Sig. (p-value):* t = 2.350 for GDP, with a Sig. = 0.047.

These test whether each coefficient is significantly different from zero. This means the GDP coefficient is statistically significant at the 5% level ($p < 0.05$). So, we can reasonably conclude that GDP has a significant positive effect on renewable energy generation. Thus, we can reject the null hypothesis and accept the alternative hypothesis.

Figure 1
SCATTER PLOT



This scatter plot shows the relationship between GDP (in trillion USD) on the x-axis and Total Renewable Energy Generation (in Terawatt-hours) on the y-axis, with a regression line fitted to the data points. The regression equation is-

Y =177.2+60.09xy = 177.2 + 60.09xy=177.2+60.09x

This indicates that for every 1 trillion USD increase in GDP, a country's total renewable energy generation increases by approximately 60.09 Terawatt-hours on average. The positive slope confirms a positive relationship between GDP and renewable energy generation. The data points are not tightly clustered around the line, which implies moderate variance in the relationship. There appear to be outliers, such as:

- A country with a very high GDP but relatively low energy generation.
- A country with moderate GDP but very high energy generation (possibly China).

These outliers weaken the overall strength of the correlation.

Further to evaluate the association between GDP and Intensity of renewable energy, the following hypothesis is being framed:

H_0: There is no correlation between GDP and renewable energy intensity.

H_1: There is a significant correlation (positive or negative) between GDP and renewable energy intensity.

Table 4
THE PEARSON CORRELATION COEFFICIENT

Correlations

		GDP (USD)	Intensity of Renewable Energy (Terawatt-hours Per Trillion USD GDP)
GDP (USD)	Pearson Correlation	1	-.171
	Sig. (2-tailed)		.638
	N	10	10
Intensity of Renewable Energy (Terawatt-hours Per Trillion USD GDP)	Pearson Correlation	-.171	1
	Sig. (2-tailed)	.638	
	N	10	10

The above table shows that the Pearson correlation coefficient table for hypothesis statement 2, examines the relationship between GDP and Intensity of Renewable Energy (TWh per trillion USD). The Pearson correlation coefficient of -171, which means there is a weak negative relation between the two variables, i.e. if GDP increases, then the intensity of renewable energy tends to decrease slightly.

Regression Analysis

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	GDP (USD)[b]	.	Enter

a. Dependent Variable: Intensity of Renewable Energy (Terawatt-hours Per Trillion USD GDP)

b. All requested variables entered.

From the above table, we can interpret that Intensity of Renewable Energy (measured in Terawatt-hours per Trillion USD GDP) is the Dependent Variable and GDP (USD) is the Independent Variable (Predictor). The method used here is the Enter method, which means all specified independent variables were entered into the model simultaneously. This table confirms that the model included GDP (USD) as the sole predictor variable to explain the variability in renewable energy intensity.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.171[a]	.029	-.092	83.69552

a. Predictors: (Constant), GDP (USD)

The above table implies that:

- R (correlation coefficient) is 0.171, which means there is a very weak positive correlation between

GDP and the intensity of renewable energy.

- The value for R-squared is 0.029, implying that only 2.9% of the variation in the Intensity of renewable energy is explained by GDP.
- Negative value of -0.092 in Adjusted R Square suggests that the model is not a good fit, and may perform worse than a model without predictors.
- Standard Error of 83.69552 implies that the predicted values (GDP) deviate from actual values by about 83.7 units.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1678.126	1	1678.126	.240	.638[b]
	Residual	56039.524	8	7004.941		
	Total	57717.650	9			

a. Dependent Variable: Intensity of Renewable Energy (Terawatt-hours Per Trillion USD GDP)

b. Predictors: (Constant), GDP (USD)

The ANOVA test was conducted to evaluate whether Gross Domestic Product (GDP) significantly predicts the Intensity of Renewable Energy. The regression model shows that GDP accounts for only a small portion of the variance in renewable energy intensity (Sum of Squares = 1678.126). The F-statistic is 0.240, with a corresponding p-value of 0.638, which is well above the conventional alpha level of 0.05.

The result indicates that the model is not statistically significant, and therefore, GDP is not a significant predictor of the intensity of renewable energy generation. Based on the ANOVA results, the null hypothesis cannot be rejected, as there is no linear relationship between GDP and

Intensity of renewable energy.

A linear regression analysis was conducted to examine the relationship between GDP (USD) and the Intensity of Renewable Energy (Terawatt-hours per trillion USD GDP). The Intensity of renewable energy (constant) is predicted as 110.389 when GDP is zero. The p-value (0.013) is statistically significant at the 0.05 level, suggesting the intercept is significantly different from zero. The unstandardized coefficient indicates that for every 1 unit increase in GDP (in trillion USD), the intensity of renewable energy is expected to decrease by 1.523 Terawatt-hours per trillion USD, holding all else constant. The standardised Beta coefficient (-0.171) shows a weak, negative relationship between GDP and energy intensity. The t-value (-0.489) and p-value (0.638) indicate that this effect is not statistically significant ($p > 0.05$). Therefore, GDP does not have a significant impact on renewable energy intensity in this model.

The regression model suggests a very weak and statistically insignificant negative relationship between GDP and renewable energy intensity. The predictor (GDP) does not contribute meaningfully to explaining variations in renewable energy intensity.

7 CONCLUSION

The findings of the Pearson correlation and linear regression analyses reveal a moderate positive and statistically significant relationship between GDP (USD) and total renewable energy generation (in Terawatt-hours). Correlation Coefficient ($r = 0.639$, $p = 0.047$) indicates that as a country's GDP increases, its renewable energy generation also tends to increase. R Square = 0.408 shows that 40.8% of the variance in renewable energy generation is explained by GDP alone. ANOVA test result ($F = 5.523$, $p = 0.047$) supports the model's overall statistical significance. The regression coefficient for GDP is statistically significant ($t = 2.350$, $p = 0.047$), confirming that GDP is a meaningful predictor of renewable energy output.

From the above study, we can predict that economically stronger nations tend to invest more in renewable energy infrastructure, likely due to higher fiscal capabilities, supportive policies, and technological access. The Study further reveals that the correlation between GDP and the intensity of renewable energy generation (Terawatt-hours per trillion USD GDP) is weak and not statistically significant. Pearson Correlation ($r = -0.171$, $p = 0.638$) shows a very weak negative relationship. R Square = 0.029 suggests GDP explains only 2.9% of the variation in renewable energy intensity. The regression coefficient for GDP is not statistically significant ($t = -0.489$, $p = 0.638$), and the overall model is insignificant ($F = 0.240$, $p = 0.638$).

Higher GDP does not necessarily translate into more efficient renewable energy use per unit of economic output. Wealthier countries may generate more total renewable energy, but they also tend to have high total energy demands, leading to lower intensity ratios. While GDP positively influences total renewable energy generation, it does not significantly predict the intensity of renewable energy use relative to economic output. This suggests that economic scale supports investment in renewables, but efficiency in utilising renewables per economic unit may depend on other factors such as energy policy, consumption patterns, and technological advancement.

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