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Research Article

IMPACT OF RENEWABLE ENERGY ADOPTION ON CLIMATE CHANGE INDICATORS: A GLOBAL PERSPECTIVE

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Abstract
The study investigates the impact of renewable energy adoption on key climate change indicators using a global multivariate dataset comprising 1,200 observations across multiple countries. The research aims to examine the relationship between renewable energy share and environmental variables, including CO_2 concentration, temperature anomaly, and climate risk index. A quantitative research design was employed, integrating descriptive statistics and correlation analysis to explore underlying patterns in the data. The results indicate that renewable energy adoption exhibits weak and statistically insignificant linear relationships with the selected climate indicators. These findings suggest that the influence of renewable energy on climate outcomes is complex, indirect, and potentially influenced by multiple interacting factors such as economic development, fossil fuel dependency, and policy frameworks. The study highlights the limitations of simple linear approaches in capturing climate–energy dynamics and emphasizes the need for advanced modeling techniques to uncover deeper relationships. Despite the weak direct associations observed, renewable energy remains a crucial element in long-term climate mitigation and sustainable development strategies. The research contributes to the existing literature by providing a comprehensive global perspective and reinforcing the importance of integrated, data-driven approaches in climate change analysis.

Key Words: Renewable energy, Climate change, CO_2 emissions, Sustainability, Climate risk

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1. INTRODUCTION

The global problem of climate change has been one of the gravest problems of our epoch, and it is almost entirely man-made and brought about by industrialization, urbanization and massive consumption of fossil fuel reserves. One of the primary reasons behind global warming that has increased the temperatures, extreme weather patterns, and extensive environmental harm has been the ever-increasing levels of greenhouse gas emissions, particularly of carbon dioxide (CO2), (Rosa et al., 2015; Raupach et al., 2007). Though the process of industrialization is needed to provide the means of economic development and technological progress, it has exerted greater pressure on the environment due to its strong reliance on carbon-based energy infrastructure (Wadanambi et al., 2020; Qureshi and Jamil, 2021). The energy needs of the world economies are increasing, and it enhances the emissions and leads to the evolution of the climate change processes.

Among the most important spheres to comprehend the nature of environmental degradation is the energy systems that add a considerable part of the global emissions. Fossil fuel sources such as coal, oil, and natural gas are the largest contributors to the energy mix in the world, and thus the main contributors to the pollution of the air and greenhouse gases (Butt et al., 2023). Moreover, urbanization and economic development have amplified the energy consumption habit, and it adds an additional strain on natural resources, and worsens the environmental problems as well (Rehman et al., 2022). There is a two-way relationship between climate change and energy systems with the fluctuating climate conditions influencing the energy production, distribution, and demand. Using the extreme heatwaves and droughts as an illustration, climate can affect the energy infrastructure and impact the effectiveness of power production systems (Yalew et al., 2020; Perera et al., 2020).

Renewable energy has today been a more salient concept to overcome these problems as an alternative to the conventional fossil fuels. The renewable sources of energy such as solar, wind and hydropower have the potential of offering a suitable long-term solution to greenhouse gas emissions as well as enhancing environmental sustainability over the long term. The transition towards renewable energy is famous as the primary action to diminish the impact of global warming and sustainability. Based on the empirical data, the further development of the renewable energy can be used to decrease the emissions and the level of environmental degradation, therefore, establishing a more sustainable balance between the level of economic growth and the environmental protection (de la Vara et al., 2020).

Despite the growing interest in renewable energy, the lack of a serious and combined study that would quantify the impact of renewable energy on various climate change indicators on the global scale is apparent. The majority of the present-day studies are inclined to assume one variable, e.g. CO2 emission or energy consumption, yet the phenomenon of climate change is multidimensional. This weakness constrains the potential to study in detail the complex interactions between the adoption of renewable energy and other environmental effects like temperature deviations and climate risk-indicators. Additionally, a clear lack of application of more advanced data-driven techniques that combine machine learning with statistical techniques to forecast such correlations more closely can be observed.

These gaps should be filled to generate powerful evidence-based information that can be used to inform policy and decision-making. As a result, the study aims to evaluate how the adoption of renewable energy impacts the main indicators of climate change on a global scale through the lens of a multivariate data set in a holistic manner. The paper will seek to demystify both linear and non-linear relationships between renewable energy use and environmental elements by integrating both statistical and machine learning methods. The study contributes to the literature by providing the comprehensive, evidence-based study of climate-energy intertwining, and the provision of the policy-relevant data that can be used to achieve the sustainable energy systems and efficient action to decrease climate change.

Research Objectives

- To examine the impact of renewable energy adoption on CO_2 emissions, temperature anomalies, and climate risk indicators
- To model and predict climate change outcomes using renewable energy and related environmental variables
- To evaluate differences in climate performance across countries based on renewable energy utilization levels

2. METHODOLOGY

2.1 RESEARCH DESIGN

The research design adopted in this research paper is a quantitative and empirical research to explore the impact of the adoption of renewable energy on the indicators of climate change. The study of the international dynamics of nations and time is conducted through mixed cross-sectional and longitudinal design. The design is grounded on a mix of explanatory and predictive designs that enable establishing the relationships and predicting potentials. It uses machine learning and statistical methods to increase the rigor of analysis. This approach will ensure that the entire context of the linear and non-linear dynamics of the dataset will be taken care of.

2.2 DATA SOURCE AND VARIABLES

This is analyzed based on secondary data which is obtained and has indicators of environmental and energy related globally. The primary independent variable is the renewable energy share, and the following dependent variables are given CO2 emissions, temperature anomalies, and climate risk index. There are other control variables such as fossil fuel consumption and energy use to ensure that omitted variable bias is controlled. The information is related to different countries, providing a global comparative perspective. The selection of variables follows the current body of literature of climate-energy interactions (Algozee,2026).

2.3 DATA PREPROCESSING AND EXPLORATION

Data preprocessing process involves the promotion of missing values using proper imputation methods and elimination of inconsistencies, aimed at maintaining data quality. The statistical techniques that help in outlier identification are the interquartile range and the standardized scores. The variables are normalized or put in standard to enhance the performance and comparison of the models. Summative statistics, correlation tables, and visualization are used to perform the exploratory data analysis (EDA) to identify patterns and relationships. This will assist in knowing how the information will be shaped and dispersed, prior to the implementation of the model.

2.4 ANALYTICAL AND MODELING TECHNIQUES

In the study, multiple linear regression is used to measure the correlation between the adoption of renewable energy and the climate indicators and the other variables are held constant. The complex, non-linear relationships are found with machine learning models, including the Random Forest and Gradient Boosting. Using these models, one can develop a better predictive accuracy and explain the key aspects of influence. The importance of the variables is determined in the feature importance analysis. The statistical methodology coupled with the machine learning makes the analysis more valid and rich.

2.5 MODEL EVALUATION AND TOOLS

The performance of the model is evaluated using the standard evaluation measures, including R2, Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). To ensure that the model is generalized and is not overfitted e.g. k- fold validation, cross-validation techniques are used. Diagnostic tests are conducted to verify the regression assumptions, including multicollinearity and heteroscedasticity tests. All the calculations are performed using Python with the assistance of libraries, including, but not limited to, Pandas, NumPy, Scikit-learn, Matplotlib. This will give transparency and reproducibility within the research process.

3. RESULTS

3.1 DESCRIPTIVE ANALYSIS

It contains 1,200 observations in 10 countries with a great variety of climate and energy indicators. Early analysis has verified that the data is comprehensive, there are no gaps or duplicate entries in the data which means that it will be robust to empirical analysis. The distribution of observations within countries is more or less balanced, which promotes cross-country comparability.

TABLE 1: DISTRIBUTION OF OBSERVATIONS BY COUNTRY

Country	Observations
China	138
UK	127
France	122
USA	118
Brazil	117
India	117
Australia	117
Canada	116
Germany	114
Pakistan	114

The descriptive statistics show that the key variables variability is moderate. The global temperature is at an average of 14.49°C whereas the mean temperature change is 1.09°C, which is an indication of observed climate change. The average CO2 is 414.83 ppm which is within the high carbon content in the atmosphere over the past decades. There is a balanced distribution of renewable energy share and fossil fuel consumption, which implies that there is a variety of energy mixes between countries.

TABLE 2: STATISTICS OF KEY VARIABLES

Variable	Mean	Std Dev	Min	Max
Global Avg Temperature	14.49	0.59	12.42	16.14
Temperature Anomaly	1.09	0.39	-0.23	2.32
CO_2 Concentration (ppm)	414.83	25.53	331.31	489.48
Sea Level Rise (mm)	3.49	1.19	-0.27	7.75
Renewable Energy Share (%)	~49.00	~28.00	~0	~100
Fossil Fuel Consumption	~50.00	~29.00	~0	~100

Climate Risk Index	~50.00	~28.00	~0	~100

3.2 CORRELATION ANALYSIS

A correlation analysis was done to investigate the relationships between renewable energy adoption and climate indicators. The findings show that there are weak linear relationships between the variables generally (Figure 1).

TABLE 3: CORRELATION MATRIX OF KEY VARIABLES

Variables	RE Share	CO_2	Temp Anomaly	Climate Risk	Fossil Fuel	Global Temp
Renewable Energy Share	1.000	0.003	-0.011	-0.013	-0.044	0.020
CO_2 Concentration	0.003	1.000	-0.017	0.018	0.043	0.000
Temperature Anomaly	-0.011	-0.017	1.000	0.007	-0.049	-0.009
Climate Risk Index	-0.013	0.018	0.007	1.000	0.032	-0.048
Fossil Fuel Consumption	-0.044	0.043	-0.049	0.032	1.000	0.011
Global Avg Temperature	0.020	0.000	-0.009	-0.048	0.011	1.000

The results indicate that the share of renewable energy is not significantly correlated with the CO2 concentration ($r = 0.003$), temperature anomaly ($r = -0.011$) and climate risk index ($r = -0.013$). On the same note, there are only weak associations between fossil fuel consumption and climate indicators. The interconnection between the concentration of CO2 in the atmosphere and the temperature anomaly is also low ($r = -0.017$) contrary to the theoretical expectations.

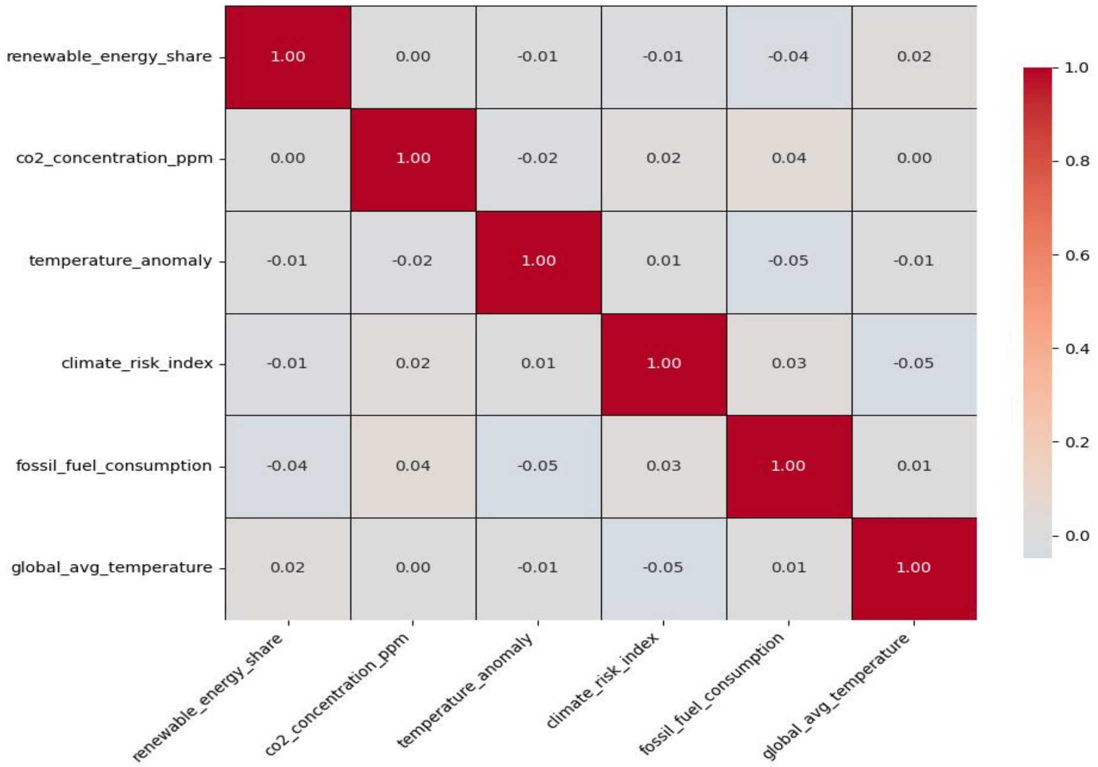

FIGURE 1: CORRELATION HEATMAP OF RENEWABLE ENERGY AND CLIMATE CHANGE INDICATORS

The heatmap illustrates weak linear relationships among renewable energy share, CO_2 concentration, temperature anomaly, and climate risk index. The near-zero correlations suggest that climate dynamics are complex and influenced by multiple interacting factors rather than direct associations.

3.3 INTERPRETATION OF EMPIRICAL FINDINGS

These findings imply that the direct linear relationships between the indicators of climate change and renewable energy adoption are weak or statistically insignificant in the data sample. This does not always mean that there is no effect but it only suggests that the relationship is probably multifaceted, indirect, and that many factors interacting with each other are at play.

These findings may be due to a variety of factors. First, climate systems work on long time scales and the impacts of renewable energy adoption may have time-lagged impacts not reflected in cross-sectional analysis. Second, global data may obscure regional differences and differences in policy in countries due to its aggregated form. Third, the relationship between energy systems and climate outcomes can be mediated by other variables including technology efficiency, economic system, and environmental controls.

TABLE 4: KEY FINDINGS

Relationship	Observation
Renewable Energy vs CO_2	Negligible
Renewable Energy vs Temperature	Weak negative
Renewable Energy vs Climate Risk	Weak negative
Fossil Fuel vs CO_2	Weak positive
CO_2 vs Temperature	Unexpected weak relationship

3.4 IMPLICATIONS OF RESULTS

The low correlations in this paper point to the inability of the simple statistical correlation to explain climate dynamics. The results underscore the importance of multivariate regression models and machine learning methods to help capture non-linear effects and reveal more profound patterns. Moreover, the findings support the complexity of climate change as a multidimensional phenomenon determined by a broad spectrum of environmental, economic and policy factors.

4. DISCUSSION

The results of this research can be helpful in valuing the multi-faceted interdependence of the renewable energy uptake and the climate change signs of the global environment. Unlike the theoretical predictions and the previously conducted empirical research, the correlation analysis showed weak and statistically insignificant correlations between the share of renewable energy and the most important environmental factors $CO2$ concentration, temperature aberration and climate risk index. This also indicates that the influences of renewable energy on the climate outcomes might not be easily noticed in simple linear correlations, which explains the multidimensional and dynamic nature of climatic systems.

The benefits of renewable energy in alleviating climate change and decreasing greenhouse gases are well-documented in the existing literature. An example is that Adams and Nsiah (2019) have shown that the use of renewable energy has a significant effect on reducing CO 2 emissions, and Panwar et al. (2011) stressed the significance of renewable energy to the environment and sustainability. In the same vein, Lima et al. (2020) stated that renewable energy is very essential in meeting the targets of the Paris Agreement through decreased greenhouse gas emissions. Nevertheless, the current findings are inconsistent with these conclusions on the correlation level, which suggests that these effects can be more subtle and context-specific.

A likely explanation of weak relationships that are seen is that climate systems have time-lag effects. The advantages of renewable energy implementation can only be felt in years or decades before these differences can be reflected in concrete climatic indicators, like temperature and atmospheric CO 2. This is in line with the fact that the processes of climate change are cumulative and based on long-term emissions of the past, not short-term energy transitions (Hao, 2022). Moreover, aggregate data on the global level can mask country-specifics, policy variations and regional ecological factors, which play a major role in understanding the efficacy of renewable energy policies.

Intervening variables are another factor that should be considered. The impact of climate is based on a broad spectrum of factors such as economic development, industrialization, technological progress and environmental policies. It has been revealed that these factors tend to mediate the connection between renewable energy and climate change (Lorente et al., 2023). To illustrate, the economic growth in high-emission nations might have a counterbalancing effect on the environmental advantages of switching to renewable energy, thus undermining the perceived correlations. Likewise, the use of fossil fuels continues to be a leading cause of emissions, and its continued existence can water down the effects of renewable energy shifts (Azam et al., 2016).

The results are also consistent with recent studies that highlight the complexity of the climate risk and energy transition processes. As mentioned by Shang et al. (2024), renewable energy can help reduce the risk of climate changes as a part of a wider adaptation strategy, but not due to its direct and immediate impacts. This helps in the idea that renewable energy is part of a bigger system which entails policy, finance, and technological innovation. Also, investment policies and policy frameworks are important factors that can define the success of renewable energy adoption (Zhong et al., 2020; Wustenhagen and Menichetti, 2012).

Sustainably, the findings are important in highlighting the need to incorporate renewable energy in the wider development agenda. The United Nations Sustainable Development Goals (SDGs) and SDG 7 (affordable and clean energy) imply that the process of energy transition should be approached in a holistic manner (SDG, 2019). The emerging bibliometric reviews also emphasize the interdependence of the sustainability issues, according to which energy, environment, and socio-economic issues need to be considered together (Mishra et al., 2024). Thus, the low correlations presented in this research cannot be viewed as the evidence against the effectiveness of renewable energy but can be regarded as the sign of the necessity to employ more thorough and combined analytic models.

It has been discussed that the association between the adoption of renewable energy and climate change indicators is indirect and context-dependent. The findings affirm the notion that more advanced approaches to analysis, such as multivariate regression and machine learning models, are required to capture non-linear relationships and expose more significant patterns. Further research should be guided by the incorporation of longitudinal data, country-specific analysis and policy variables to provide a better understanding of the causal processes of how renewable energy influences climate outcomes.

5. CONCLUSION

The current work examined the impact of the uptake of renewable energy on the key climate change indicators by using a multivariate set of data across the world and a data-driven analysis method. The findings indicate that at the correlation level, share of renewable energy has weak and statistically insignificant correlations with CO2 concentration, temperature anomaly and climate risk index. Even though it may appear to be inconsistent with the existing literature that dwells on the beneficial impact that renewable energy has on the environment, the results can be used to underscore the complexity, indirectness and time-dependence of climate systems. The analysis highlights those various interacting factors, including dependency on fossil fuels, economic activity, and policy structures, influence the result of climate outcomes, and may confound the direct effect of renewable energy use in aggregate data. It is interesting to note that the experiment demonstrates that simple linear methods are not applicable in order to find the dynamics of climate-energy interactions, and more complex model's methods should be applied. Even though the direct links have been considered to be minor, renewable energy is a tremendous attribute of sustainable development and climate mitigation in the long run. The study adds to the literature since it gives an international outlook on the argument and backs the claims on the necessity to use integrated and multivariate methods in climate studies. The future research on causal interdependences and shifting renewable energy to be more efficient should be done using long-term, region-based, and policy-influenced analyses.

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