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Development or environmental sustainability? Investigating the relationship between poverty rate and carbon emissions using the K-nearest neighbor algorithm

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Abstract

This paper applies the k-nearest neighbor (k-NN) algorithm, recognized for its predictive accuracy, to investigate the relationship between global poverty rates and global carbon emissions. The analysis explores how variations in poverty levels influence environmental carbon emissions. The results demonstrate that the relationship between poverty rates and carbon emissions resembles the production possibility curve, showing an inverse relationship: as poverty rates increase, carbon emissions decrease. Specifically, the k-NN model reveals that a 1% rise in poverty rates leads to a 0.29% reduction in carbon emissions. This outcome reflects the tendency for emissions to fall when economic growth slows. The study concluded that the global quest to eradicate poverty is closely linked to environmental challenges. While reducing poverty contributes to improved living standards, it also threatens to increase emissions, necessitating a balance between economic growth and environmental sustainability. The findings highlight the urgent need for policies that reconcile poverty reduction and environmental conservation. A key recommendation is to rely heavily on renewable energy to support economic growth while reducing carbon emissions. This approach enables progress toward poverty reduction and environmental protection.

Keywords: CO_2 emissions, Global poverty rate, K-nearest neighbor algorithm, Machine learning algorithms.

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1. Introduction

Maintaining environmental sustainability while balancing economic growth poses a significant global challenge. As nations pursue economic development, concerns regarding environmental impacts—especially carbon emissions—are growing. Climate change is primarily driven by carbon dioxide (CO_2) emissions, which are often linked to energy consumption, industrial activities, and various commercial operations. At the same time, poverty continues to be a significant issue for millions around the globe, leading governments and international organizations to aim for its elimination. Understanding the relationship between poverty levels and carbon emissions is essential for developing effective policies that promote both economic development and environmental sustainability.

Poverty and environmental degradation are closely linked. Economic growth can reduce poverty by creating jobs and enhancing living standards; however, it may also result in increased CO_2 emissions from industrial processes, deforestation, and energy use. On the other hand, high poverty levels often restrict access to clean, sustainable energy, forcing communities to depend on harmful practices like burning biomass and causing further deforestation. This paradox raises an important question: Can alleviating poverty inevitably lead to higher carbon emissions, or can we achieve sustainable economic growth while reducing environmental impact?

Theoretical perspectives on the connection between poverty and carbon emissions present differing views. The Environmental Kuznets Curve (EKC) hypothesis posits that environmental degradation initially rises as economies develop. Once societies reach a specific income level, they adopt cleaner technologies and enforce stricter environmental regulations, reducing emissions. Nonetheless, the empirical evidence regarding this connection remains ambiguous and is shaped by geographic, economic, and policy variables. Some studies suggest that poverty alleviation efforts—such as enhancing infrastructure and increasing access to education and healthcare—can promote environmental sustainability. On the other hand, other studies argue that heightened economic activity will inevitably increase carbon emissions.

This study explores how poverty rates relate to CO_2 emissions by employing the K-Nearest Neighbor (KNN) algorithm. This machine-learning approach allows us to detect patterns and relationships in data that conventional statistical techniques might miss. By utilizing KNN, we can evaluate how various poverty levels correspond to fluctuations in carbon emissions and examine the feasibility of creating a predictive model to guide policy decisions. This study highlights historical data to illuminate past trends and assess the potential effects of poverty reduction programs on environmental sustainability.

This study provides valuable insights for policymakers, environmental advocates, and economists striving to align economic growth with ecological accountability. We employ machine learning techniques to enhance our comprehension of the relationship between poverty and emissions, promoting evidence-based policies that encourage development and environmental sustainability. This research explores a crucial question: Can poverty alleviation and carbon emission control coexist within a sustainable development framework?

Moreover, tackling the gap in access to clean energy is vital for mitigating the environmental effects of poverty. Many low-income communities depend on fossil fuels and biomass to satisfy their daily energy needs, significantly increasing carbon emissions. Governments and global organizations must enact specific policies that promote a shift towards renewable energy sources in underprivileged areas. Investing in clean energy infrastructure and encouraging energy-efficient technologies can alleviate poverty while minimizing environmental harm.

A comprehensive approach that includes social, economic, and environmental factors is essential for sustainable development. Improving education and vocational training can empower individuals to participate in green economies and adopt sustainable practices. Policymakers must collaborate with industry leaders, researchers, and community groups to create inclusive strategies that foster equitable economic growth while minimizing environmental impact. This study offers actionable insights within a thorough framework to support a balanced and sustainable future.

2. Literature Review

Many studies have explored the links between poverty, environmental damage, and economic factors. For example, Khobai, et al. [1] examined the relationship between poverty and carbon emissions in South Africa with an ARDL bounds test. Their goals included evaluating the long-term connection between these two variables, and the findings confirmed a significant relationship, showing that carbon emissions significantly contribute to poverty in South Africa. Similarly, Mahamanea, et al. [2] sought to assess how reducing CO_2 emissions affects poverty in less developed countries, mainly through green structural transformation. Their results suggested that lowering CO_2 emissions might increase poverty in LDCs and showed a negative correlation between CO_2 emissions and poverty rates. Li, et al. [3] examined the link between poverty alleviation and carbon emissions, providing policy suggestions for sustainable development. They found that while poverty alleviation might increase carbon emissions through consumption and production, efforts to reduce carbon emissions can negatively impact poverty alleviation in an inverted U-shaped relationship.

Numerous studies have focused on the intricate relationships among poverty, emissions, the environment, and economics. Utilizing the STIRPAT model, Khan [4] empirically assessed the "three Zeros" in the Asia-Pacific region. This study aimed to evaluate sustainable development objectives and concluded that poverty contributes to increased CO_2 emissions, exacerbating environmental degradation. Conversely, a higher unemployment rate tends to reduce environmental harm, and technological advancements play a role in mitigating degradation. Similarly, Bekun, et al. [5] studied poverty's effects on environmental degradation in MINT economies, showing that poverty in Türkiye results in environmental damage. However, contrasting effects were observed in Nigeria, Indonesia, and Mexico. Furthermore, Duong and Flaherty [6] examined the relationships between economic growth, income inequality, and carbon emissions, concluding that financial development reduces poverty and exacerbates contributions to income inequality issues.

Numerous studies have examined how inclusive finance, industrial structure, and technological innovation affect the poverty-environment relationship. Ngong, et al. [7] investigated the nexus between greenhouse gas emissions and poverty alleviation in the West African States, revealing that while CO_2 emissions are positively (but not significantly) related to GDP per capita, methane emissions have a negative impact. Yu and Liu [8] examined the intricate relationship between poverty and CO_2 emissions in China, showing that the effect of poverty on emissions evolves. Conversely, inclusive finance consistently reduces CO_2 emissions. Malerba [9] also developed a composite index that merges emissions and poverty, indicating that the carbon intensity associated with poverty reduction differs by country. Notably, economic growth negatively affects this intensity until a certain threshold is reached, which starts to increase.

Further research has enhanced the literature by incorporating regional and thematic perspectives. Derouez, et al. [10] analyzed renewable energy and circular economy strategies in China and the European Union, discovering that China has been more successful in cutting emissions through solar and wind power, while the strategy affects poverty reduction differently across the regions. Khan and Yahong [11] examined the asymmetric impact of poverty, income inequality, and population on carbon emissions in Pakistan, concluding that poverty and population increases contribute to higher carbon emissions. In contrast, income inequality mitigates environmental degradation in the long run. The 2022 report "Poverty, Inequality, and the Decarbonization of Economic Development" analyzed household poverty, inequality, and greenhouse gas emissions. It concluded that carbon taxes in Mexico result in slight welfare losses, whereas changes in energy prices substantially affect both emissions and welfare in Indonesia.

The environmental consequences of trade and industrial policies have been a vital research focus. Khan [12] examined the links between Southeast Asia's carbon emissions, poverty, economic growth, and logistics. He found that poverty and logistical operations are significant in environmental harm, while advancements in these areas could help alleviate degradation. Rizk and Slimane [13] examined the connections between poverty, the environment, and institutions, uncovering a nonlinear relationship between poverty and CO_2 emissions. They stressed that enhancing institutional quality can diminish both poverty and environmental damage. Andrée, et al. [14] reevaluated the global relationships between economic growth and environmental health, concluding that while development enhances resource efficiency, it is insufficient for long-term environmental sustainability, prompting a call for urgent global preservation initiatives.

Additional research has explored the link between poverty and the environment from different regional angles. Rai [15] investigated the intricate dynamics of the poverty-environment relationship through the lens of sustainable development, highlighting the necessity for robust policies. Mirza, et al. [16] concentrated on the coastal region of Pakistan, revealing a significant long-term correlation between poverty and environmental decline, characterized by a two-way relationship between environmental factors and poverty. Bruckner, et al. [17] examined the impact of poverty alleviation on national and global carbon emissions, concluding that while poverty alleviation remains relatively small worldwide, it can quadruple carbon emissions in low- and lower-middle-income countries. Ssekibaala and Kasule [18] identified a cyclical relationship influenced by internal and external factors in their study of the relationship between poverty and environmental degradation in Sub-Saharan Africa. Majeed, et al. [19] performed a bibliometric analysis of poverty reduction and sustainable development in the Global South, pinpointing key thematic clusters that connect sustainability to poverty alleviation.

In addition to these studies, Alam [20] explored the causal connections between population, poverty, and environmental degradation in India, highlighting the structural shifts that occurred before and after reforms. Data from Pakistan provided by Zaman, et al. [21] show a long-term relationship between poverty, air pollution, and population growth. Scott [22] investigated the link between chronic poverty and the environment from a vulnerability perspective, suggesting that environmental factors should be included in poverty studies and underscoring key themes for further research. Parikh [23] analyzed the connection between poverty, environment, and development, emphasizing the significance of property rights and population growth. In Ojha [24] investigated methods to lower carbon emissions and reduce poverty in India. He found that implementing domestic carbon tax policies might hinder economic growth and exacerbate poverty. Alternatively, he suggested that tradable emission permits present a more beneficial option. Ali, et al. [25] analyzed the relationship among Pakistan's energy consumption, economic liberalization, financial development, poverty levels, and carbon emissions. Their findings indicated both long-term and short-term causal connections. Additionally, Sarkar [26] emphasized the effects of climate change on worldwide poverty and inequality. Reed [27] highlighted the challenges that globalization poses to sustainable development. In contrast, Kassa, et al. [28] explored the connection between poverty in Ethiopia and environmental factors. Antle and Stoorvogel [29] also investigated how agricultural carbon sequestration supports sustainability and reduces poverty, demonstrating that carbon contracts can enhance rural incomes and mitigate soil carbon loss. However, the success of these contracts depends on the payment amounts and processes involved.

This study distinguishes itself from earlier research by integrating advanced machine learning techniques with traditional econometric methods to analyze bilateral trade flows. While previous studies primarily relied on static theoretical models and separate econometric approaches, our method utilizes various economic, demographic, and geographic factors, taking advantage of the predictive power of algorithms such as gradient boosting and random forest. This combination improves the robustness and accuracy of our results and reveals complex non-linear relationships that traditional methods may overlook.

Moreover, unlike many past investigations that focused on single aspects of trade determinants or were limited by narrow data scopes, our study adopts a holistic framework by combining panel data analysis with machine learning. This method facilitates the delivery of descriptive and predictive insights, enhancing our understanding of the elements affecting bilateral trade between Egypt and the BRICS countries. This integration benefits policymakers, leading to more practical recommendations for addressing global economic issues.

Our study extends the existing literature by bridging the gap between traditional economic theory and modern data science. Doing so offers a richer, more nuanced perspective on trade determinants and paves the way for future research that further refines policy strategies for sustainable international trade.

3. Empirical framework

This paper investigates the relationship between the global poverty rate as the independent variable and global CO2 emissions as the dependent variable. The natural logarithm is used to transform all variables due to the extensive range of values in the data and the possibility of heteroscedasticity. The following are the specifications for the regression model:

$$\ln(\text{Global } CO_2) = \ln(\text{poverty rate})$$

Where,

- Ln (global CO2) represents the natural logarithm of global CO2 emissions (dependent variable).
- Ln (global poverty rate): denotes the natural logarithms of poverty rate (independent variable).

4. Data

This study utilizes data from the World Bank database covering 1984 to 2022. Since the dataset includes annual records, a comprehensive longitudinal analysis of patterns over nearly 40 years is feasible. The two primary variables of the study are:

- Independent Variable: The global poverty rate is indicated as a percentage of the population.
- Dependent Variable: Global carbon dioxide (CO2) emissions, measured in metric tons (Mt CO2e).

The analysis was improved by applying the natural logarithm to both variables. This change clarifies statistical interpretations, reduces skewness, and normalizes the data distribution. Additionally, it boosts the K-Nearest Neighbor (KNN) algorithm's performance by fostering linear correlations between the variables and stabilizing variance, the data shown in the scatter plot in Figure 1.

The World Bank is our preferred data source as it ensures comparability, consistency, and reliability. This dataset offers insights into the changing relationships between global poverty rates and carbon emissions by revealing patterns that can guide policymakers. Recognizing the essential roles that environmental sustainability and economic development play in global governance, this study employs machine learning techniques to evaluate the impact of poverty reduction programs on carbon emissions. It explores the potential for achieving sustainable development without exacerbating environmental harm.

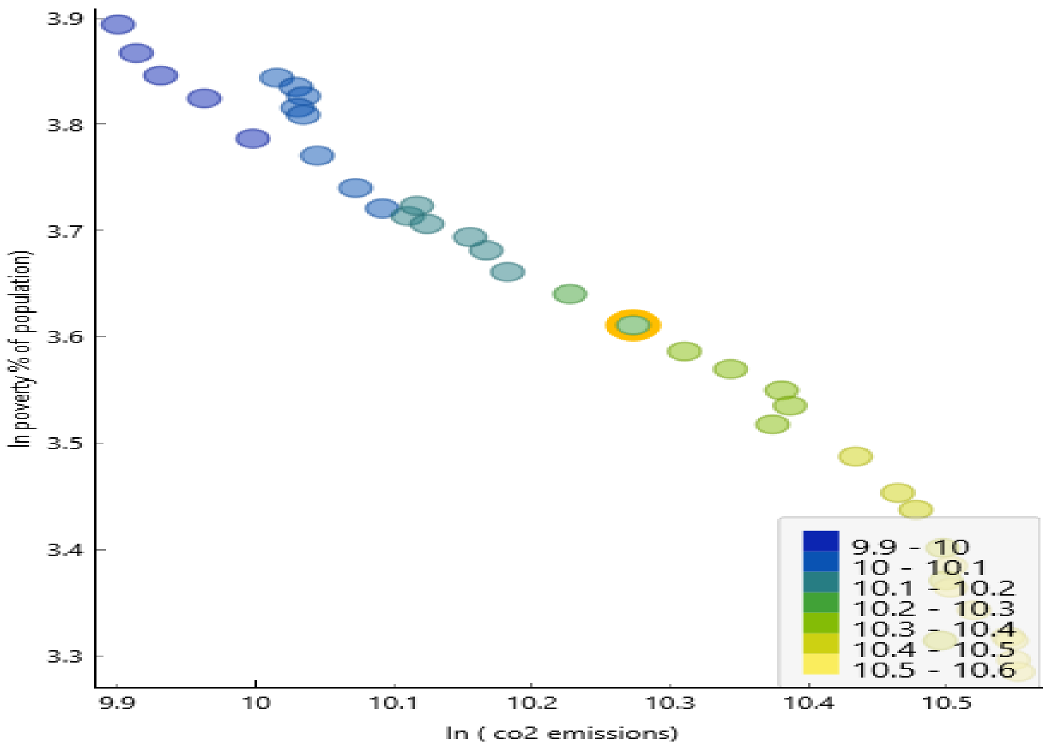

Figure 1.
Scatter plot for the variables.

Figure 1 shows that the curve representing the relationship between the poverty rate and carbon emissions in the world is very similar to the production potential curve. Therefore, we can assert that the relationship between the two variables is inverse: as poverty rates increase, carbon emissions decrease. This is a natural result, as emissions decrease in the event of a reduction in economic growth. The question remains: How much will carbon emissions be reduced if poverty rates increase by 1%? We will discuss this in the following lines.

5. Methodology

KNN is a popular instance-based, nonparametric machine-learning technique for classification and regression applications. In regression scenarios, KNN forecasts a continuous target variable based on the average values of the K closest data points in the feature space. This strategy helps process complex and nonlinear datasets since it is based on the notion that adjacent data points have similar characteristics [30].

5.1. Distance Metrics

KNN regression uses a chosen distance measure to assess related data points. The following are the distance functions that are most frequently used:

- Euclidean Distance:

$$d(x_i, x_j) = \sqrt{\sum_{k=1}^{n} (x_{ik} - x_{jk})^2}$$

- Manhattan Distance:

$$d(x_i, x_j) = \sum_{k=1}^{n} |x_{ik} - x_{jk}|$$

- Minkowski Distance (Generalized Form):

$$d(x_i, x_j) = \left(\sum_{k=1}^{n} |x_{ik} - x_{jk}|^p\right)^{\frac{1}{p}}$$

Depending on the type of data, the model's performance is significantly impacted by the distance measure selection.

5.2. Prediction Function in KNN Regression

The predicted value $\hat{y}$ for a new data point is calculated using the formula below once the K-nearest neighbors have been identified**:**

$$\hat{y} = \frac{1}{K}\sum_{i=1}^{K} y_i$$

Where y_i refers to the target values of the K-nearest neighbors.
On the other hand, closer neighbors are given higher weights in distance-weighted KNN regression:

$$\hat{y} = \frac{\sum_{i=1}^{K} w_i y_i}{\sum_{i=1}^{K} w_i}$$

Where the weight w_i is frequently thought of as being the opposite of distance:

5.3. Model Evaluation Metrics

The performance of KNN regression is assessed using several error measures:

- Mean Squared Error (MSE):

$$MSE = \frac{1}{n}\sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

- Root Mean Squared Error (RMSE):

$$RMSE = \sqrt{MSE}$$

- Mean Absolute Error (MAE):

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |y_i - \hat{y}_i|$$

- R-squared (R^2):

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2}$$

As Table 1 illustrates, better model performance is indicated by a lower MSE or RMSE and a higher R^2 value.

Table 1.
The ML algorithms prediction.

Model	MSE	RMSE	MAE	R2
KNN	0.001	0.030	0.002	0.981
GB	0.001	0.034	0.027	0.975
SVM	0.004	0.061	0.053	0.920
RF	0.001	0.031	0.024	0.979
DT	0.001	0.037	0.029	0.970

Table 2 demonstrates that the KNN algorithm is more accurate than the others, with a larger R2 and the lowest MSE. As a result, the paper uses KNN to calculate local regression coefficients, as Table 2 illustrates.

Table 2.
The nearest neighbors' data estimates the local regression coefficients.

KNN Feature selection	Score
The global poverty rate	-0.294646

Table 2 shows that increasing poverty rates by 1% decreases carbon emissions by 0.29%. This result represents a dilemma for the whole science of development and poverty eradication. To address this, it is necessary to rely on renewable energy to increase economic growth rates and, thus, alleviate poverty.

6. Conclusion

This study utilized the K-Nearest Neighbor (KNN) algorithm to investigate the connection between global poverty rates and carbon dioxide emissions from the industrial sector. The results indicate a strong inverse relationship between these factors, implying that rising poverty rates coincide with declining carbon emissions. This surprising observation highlights the intricate dynamics between economic growth and environmental consequences. While economic development usually leads to increased energy use and emissions, higher poverty rates may be linked to diminished industrial activity and, consequently, lower emissions. Applying machine learning techniques, particularly KNN, showcased its capacity to capture nonlinear relationships and offered reliable predictive insights that conventional econometric models may fail to identify.

The findings reveal a significant challenge in global development policies: strategies to alleviate poverty and boost economic growth might unintentionally increase carbon emissions. Conversely, efforts focused on emission reduction could hinder economic advancement. Therefore, these results underscore policymakers' need to embrace a balanced strategy that promotes sustainable economic development. Specifically, a shift towards renewable energy sources and integrating energy-efficient technologies in industrial practices can aid in separating economic growth from environmental harm. This policy framework is crucial for reaching sustainable development objectives, ensuring that efforts to reduce poverty and enhance environmental sustainability are compatible goals. Additionally, this study's novel use of the KNN algorithm enhances existing literature by offering a data-driven approach to examining the connection between poverty and the environment. The effectiveness of this method indicates that upcoming research should combine cutting-edge machine learning techniques with conventional economic analyses to understand intricate socio-economic dynamics better. Policymakers and stakeholders can leverage these insights to create effective strategies harmonizing economic progress with environmental sustainability. This research provides a robust basis for future studies and policy initiatives to foster sustainable growth in a progressively interconnected global economy.

This study also creates exciting opportunities for future research by emphasizing how advanced machine-learning techniques can enhance our understanding of the intricate relationships between economic and environmental factors. Future research could build on this analysis by adding more datasets, testing different machine learning models like deep neural networks, and investigating regional differences within and across countries. These efforts would yield more profound insights into causal mechanisms and enable more detailed policy suggestions. Additionally, addressing the current study's limitations—such as data limitations and potential biases in the models—is crucial for developing strong, evidence-based strategies for sustainable development. Pursuing these future directions will enrich academic discussions and provide policymakers with improved tools to reconcile economic growth with environmental sustainability in a rapidly changing global economy.

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