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Renewable Energy Consumption and CO₂ Emissions: A Comparative Study of China, Germany, India, Japan, and the United States (1990–2019)

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ABSTRACT :

The increasing concentration of carbon dioxide (CO₂) emissions has intensified global concerns regarding climate change, highlighting the importance of renewable energy in achieving sustainable development. This study examined the relationship between the share of renewable energy consumption and CO₂ emissions in China, Germany, India, Japan, and the United States during 1990–2019. Secondary data were obtained from the World Bank's World Development Indicators (WDI) database. Renewable energy consumption was measured as the percentage of total final energy consumption, while CO₂ emissions were expressed in kilotonnes (kt). Statistical analyses, including trend analysis, descriptive statistics, Pearson correlation, simple linear regression, and percentage change analysis, were conducted using Microsoft Excel 2021. The results indicated that Germany, Japan, and the United States increased their renewable energy share, whereas China and India experienced declines in the renewable energy share over the study period. China and India showed substantial increases in CO₂ emissions, while Germany recorded a significant reduction. Strong negative correlations were observed for China ($r = -0.957$), Germany ($r = -0.939$), and India ($r = -0.978$), whereas weaker relationships were found for Japan and the United States. The findings demonstrate that the relationship between renewable energy share and CO₂ emissions varies across countries and is influenced by broader economic and energy-system factors, providing useful insights for sustainable energy policy and future research.

Keywords: Renewable energy consumption, CO₂ emissions, World Bank, Pearson correlation, linear regression, Sustainable energy, Climate change.

1. Introduction:

Climate change has emerged as one of the most significant environmental challenges of the twenty-first century, posing serious threats to ecosystems, economies, and human well-being worldwide. The rapid increase in atmospheric greenhouse gas (GHG) concentrations, primarily carbon dioxide (CO₂), has been identified as the principal driver of global warming. Human activities such as fossil fuel combustion, industrial production, transportation, and deforestation have substantially increased CO₂ emissions over the past few decades, accelerating climate change and contributing to rising global temperatures, sea-level rise, and extreme weather events (Intergovernmental Panel on Climate Change [IPCC], 2023). According to the IPCC (2023), limiting global warming to 1.5°C above pre-industrial levels requires immediate and substantial reductions in greenhouse gas emissions, with a transition toward low-carbon and renewable energy systems playing a central role. The global energy sector is responsible for approximately three-quarters of anthropogenic greenhouse gas emissions, making it the largest contributor to climate change (International Energy Agency [IEA], 2021). The continued dependence on fossil fuels, including coal, oil, and natural gas, has significantly increased CO₂ emissions despite remarkable technological and economic progress. Consequently, governments, policymakers, and international organizations have emphasized the need to increase renewable energy utilization as a sustainable strategy for reducing carbon emissions while meeting growing energy demands (International Renewable Energy Agency [IRENA], 2023).

Renewable energy sources, including solar, wind, hydropower, biomass, and geothermal energy, are regarded as environmentally sustainable alternatives to conventional fossil fuels because they produce little or no direct greenhouse gas emissions during electricity generation. Increasing the share of renewable energy in national energy systems can contribute to improved energy security, enhanced environmental quality, and long-term economic sustainability (IRENA, 2023). As countries strive to achieve the Sustainable Development Goals (SDGs), particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), renewable energy has become an essential component of national and international climate policies (United Nations, 2023). Although renewable energy deployment has expanded considerably over the last three decades, the relationship between renewable energy consumption and CO₂ emissions varies among countries due to differences in economic development, industrialization, population growth, technological advancement, and energy policies. Developed countries such as Germany and Japan have implemented comprehensive renewable energy

policies aimed at reducing greenhouse gas emissions, whereas rapidly developing economies such as China and India continue to experience increasing energy demand associated with industrial and economic growth. The United States, one of the world's largest energy consumers, has also undergone significant changes in its energy mix over recent decades. Therefore, understanding the statistical relationship between renewable energy consumption and CO₂ emissions across different countries is essential for evaluating the effectiveness of renewable energy policies and identifying future pathways toward sustainable development.

Several studies have investigated the relationship between renewable energy consumption and environmental quality. Shafiei and Salim (2014) reported that increased renewable energy consumption contributes to reducing CO₂ emissions in OECD countries, whereas fossil fuel consumption significantly increases emissions. Similarly, Zoundi (2017) found that renewable energy development plays an important role in mitigating carbon emissions across African countries. More recently, Voumik et al. (2023) observed that renewable electricity generation has a significant influence on reducing CO₂ emissions among G7 countries. Perone (2024) further demonstrated that expanding renewable energy production contributes to long-term reductions in carbon emissions in OECD nations. These studies collectively highlight the importance of renewable energy in addressing climate change; however, the magnitude and direction of this relationship differ depending on country-specific socioeconomic and energy characteristics. Despite extensive research on renewable energy and carbon emissions, comparatively fewer studies have simultaneously examined long-term trends, descriptive statistics, correlation analysis, regression analysis, and percentage change analysis using a consistent dataset across both developed and developing economies. Comparative studies involving China, Germany, India, Japan, and the United States are particularly valuable because these countries represent diverse stages of economic development, energy transitions, and emission profiles. Such analyses can provide insights into how renewable energy consumption has evolved over time and how it is statistically associated with CO₂ emissions under different national contexts.

The present study addresses this gap by conducting a comparative statistical analysis of renewable energy consumption and CO₂ emissions in five major economies China, Germany, India, Japan, and the United States during the period 1990–2019. Renewable energy consumption is measured as the percentage of total final energy consumption, while CO₂ emissions are expressed in kilotonnes (kt). Secondary data obtained from the World Bank's World Development Indicators database were analyzed using descriptive statistics, trend analysis, Pearson correlation analysis, simple linear regression, and percentage change analysis. These statistical techniques provide a comprehensive assessment of temporal trends and relationships between renewable energy consumption and CO₂ emissions. The findings of this study are expected to contribute to the understanding of renewable energy transitions and their association with carbon emissions in countries with different energy structures and development pathways. The results may also assist policymakers, researchers, and energy planners in evaluating the effectiveness of renewable energy policies and developing strategies for reducing greenhouse gas emissions while ensuring sustainable energy development.

Objectives of the Study

The objectives of this study are:

1. To analyze the trends in renewable energy consumption and CO₂ emissions in China, Germany, India, Japan, and the United States during the period 1990–2019.
2. To compare the descriptive statistics of renewable energy consumption and CO₂ emissions among the selected countries.
3. To examine the relationship between renewable energy consumption and CO₂ emissions using Pearson correlation analysis.
4. To evaluate the impact of renewable energy consumption on CO₂ emissions using simple linear regression analysis.
5. To assess the percentage change in renewable energy consumption and CO₂ emissions between 1990 and 2019.

2. Literature Review

The increasing concern over climate change and global warming has led to extensive research on the relationship between renewable energy consumption and carbon dioxide (CO₂) emissions. Numerous studies have investigated whether increasing the share of renewable energy can reduce greenhouse gas emissions while supporting economic growth. However, the magnitude and direction of this relationship differ across countries due to variations in energy policies, economic development, industrialization, and technological advancement.

Shafiei and Salim (2014) examined the relationship between renewable and non-renewable energy consumption and CO₂ emissions in OECD countries using panel data analysis. Their study revealed that renewable energy consumption significantly contributes to reducing CO₂ emissions, whereas non-renewable energy consumption increases environmental degradation. The authors concluded that promoting renewable energy technologies is essential

for achieving sustainable development and reducing carbon emissions.

Zoundi (2017) analyzed data from 25 African countries to investigate the relationship between renewable energy consumption and environmental quality using the Environmental Kuznets Curve (EKC) framework. The results indicated that renewable energy consumption significantly reduced CO₂ emissions, highlighting the importance of renewable energy in mitigating climate change. The study emphasized that government support for renewable energy investment is necessary to improve environmental sustainability.

Nathaniel and Khan (2020) investigated the effects of renewable energy consumption, trade, and urbanization on the ecological footprint in ASEAN countries. Their findings showed that increasing renewable energy consumption improved environmental quality by reducing carbon emissions and ecological degradation. The authors suggested that renewable energy development should be integrated into national energy policies to achieve long-term sustainability.

Sovacool et al. (2020) compared countries pursuing renewable electricity generation with those relying on nuclear energy for carbon reduction. Their analysis demonstrated that countries investing heavily in renewable electricity generally achieved greater reductions in CO₂ emissions than countries primarily dependent on nuclear power. The study concluded that renewable energy expansion plays a critical role in achieving global climate goals.

Wagner (2021) statistically analyzed the relationship between renewable energy, nuclear energy, and CO₂ emissions using European and global datasets. The study found that countries with higher renewable energy penetration generally exhibited lower carbon emissions, although the strength of the relationship varied depending on economic and technological conditions. The research highlighted that renewable energy alone cannot completely explain emission trends because economic growth and industrial activities also influence CO₂ emissions.

The International Energy Agency (IEA, 2021) emphasized that achieving global net-zero emissions by 2050 requires rapid expansion of renewable energy technologies, improvements in energy efficiency, and a gradual reduction in fossil fuel dependence. According to the report, renewable energy will contribute significantly to future electricity generation and carbon emission reduction strategies worldwide.

The Intergovernmental Panel on Climate Change (IPCC, 2023) reported that limiting global warming to 1.5°C requires immediate reductions in greenhouse gas emissions across all economic sectors. The report identified renewable energy as one of the most effective mitigation strategies for reducing anthropogenic CO₂ emissions while supporting sustainable economic development.

Voumik et al. (2023) investigated the impact of renewable and non-renewable electricity generation on CO₂ emissions in G7 countries using static and dynamic panel estimation techniques. Their findings indicated that renewable electricity generation significantly reduced carbon emissions, whereas fossil fuel-based electricity generation contributed to increasing emissions. The study recommended accelerating renewable energy investments to achieve climate targets.

The International Renewable Energy Agency (IRENA, 2023) reported that renewable energy capacity has expanded rapidly over the last decade, particularly in solar and wind energy. However, the report emphasized that global renewable energy deployment must accelerate further to achieve international climate goals and reduce greenhouse gas emissions substantially.

Perone (2024) examined the long-term relationship between renewable energy production and CO₂ emissions across 27 OECD countries using panel cointegration and Granger causality techniques. The results confirmed that increasing renewable energy production contributes to long-term reductions in CO₂ emissions. The study further highlighted that renewable energy policies combined with technological innovation significantly improve environmental performance.

Although previous studies have established a relationship between renewable energy consumption and CO₂ emissions, most investigations have focused either on specific regions such as OECD, G7, ASEAN, or African countries, or have employed advanced econometric methods such as panel regression and cointegration analysis. Comparative statistical analyses using descriptive statistics, trend analysis, correlation, regression, and percentage change across both developed and developing economies remain relatively limited. Therefore, the present study compares China, Germany, India, Japan, and the United States over the period 1990–2019 using a consistent statistical framework. By combining trend analysis, descriptive statistics, Pearson correlation, simple linear regression, and percentage change analysis, this study provides a comprehensive comparison of renewable energy consumption and CO₂ emission patterns among countries with different energy structures and development pathways.

Research Gap

Most previous studies have focused on regional analyses or advanced econometric techniques to investigate the relationship between renewable energy consumption and CO₂ emissions. Limited studies have provided a straightforward comparative statistical analysis of both developed and developing countries using publicly available World Bank data over a long time period. Furthermore, few studies integrate trend analysis, descriptive statistics, Pearson correlation, simple linear regression, and percentage change analysis within a single framework. This study addresses these gaps by comparing China, Germany, India, Japan, and the United States using a consistent dataset for the period 1990–2019 and applying multiple statistical techniques to better understand the relationship between renewable energy consumption and CO₂ emissions.

3. Materials and Methods

3.1 Data Description

Annual panel data spanning from 1990 to 2019 (T = 30 observations per country) were compiled for five major economies: China, Germany, India, Japan, and the United States. The primary variables in this study include Renewable Energy Share (REE), measured as a percentage of total final energy consumption (%), and Carbon Dioxide (CO₂) emissions, measured in kilotons (kt). The complete 1990–2019 dataset utilized in this analysis is provided in Appendix A.

3.2 Data Source

The study utilized secondary annual data obtained from the World Bank Open Data (World Development Indicators - WDI) database. The World Bank provides internationally standardized and validated socioeconomic, environmental, and energy-related indicators, making it a reliable source for cross-country comparisons. The study covered a 30-year period (1990–2019).

3.2.1 The datasets were downloaded from:

- Renewable Energy Consumption (% of total final energy consumption) <https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS>
- CO₂ Emissions (kt) <https://data.worldbank.org/indicator/EN.ATM.CO2E.KT>

The downloaded datasets were filtered to include only the selected countries and years. Data processing and statistical analyses were performed using Microsoft Excel 2021.

3.3 Study Area

Five countries were selected for comparative analysis based on their economic importance, energy consumption patterns, and renewable energy development.

The selected countries were:

- China
- Germany
- India
- Japan
- United States

These countries represent both developed and developing economies and exhibit diverse energy policies, industrial structures, and renewable energy adoption levels. China, India, and the United States are among the world's largest CO₂ emitters, while Germany is recognized for its renewable energy transition (Energiewende), and Japan has implemented significant energy policy reforms following the Fukushima nuclear accident.

3.4 Variables Used in the Study

Two variables were selected for the statistical analysis.

i) Independent Variable (X): Renewable Energy Consumption

- Indicator Name: Renewable energy consumption (% of total final energy consumption)
- Unit: Percentage (%)
- World Bank Indicator Code: EG.FEC.RNEW.ZS

Renewable energy consumption represents the proportion of total final energy consumption supplied by renewable energy sources such as hydropower, solar, wind, geothermal, and biomass.

ii) Dependent Variable (Y): Carbon Dioxide (CO₂) Emissions

- Indicator Name: CO₂ emissions
- Unit: Kilotonnes (kt)
- World Bank Indicator Code: EN.ATM.CO2E.KT

CO₂ emissions represent carbon dioxide released primarily from fossil fuel combustion and cement production.

Table No. 3.1: Variables Used in the Study

Variable	Type	Unit
Renewable Energy Consumption	Independent Variable	% of total final energy consumption
CO ₂ Emissions	Dependent Variable	Kilotonnes (kt)

3.5 Data Processing

The collected data were arranged country-wise in Microsoft Excel. Data cleaning included:

- Verification of missing observations.
- Removal of unnecessary variables.
- Organization of annual observations from 1990 to 2019.
- Preparation of separate datasets for renewable energy consumption and CO₂ emissions.

The processed data were subsequently used for graphical representation and statistical analysis.

3.6 Statistical Methods

Statistical analyses were performed using Microsoft Excel 2021. The analyses included trend analysis, descriptive statistics, Pearson correlation analysis, simple linear regression, and percentage change analysis.

3.6.1 Trend Analysis

Line graphs were prepared to illustrate the temporal variation in renewable energy consumption and CO₂ emissions for each country from 1990 to 2019. The graphical analysis was used to identify increasing or decreasing trends over the study period.

3.6.2 Descriptive Statistics

Descriptive statistics were calculated to summarize the characteristics of the datasets. The following statistical measures were determined:

- Mean
- Standard deviation

- Minimum
- Maximum

The arithmetic mean was calculated as:

$$\bar{X} = \frac{\sum_{i=1}^n X_i}{n}$$

where

- $\bar{X}$ = Mean
- X_i = Individual observation
- n = Number of observations

The standard deviation was calculated as:

$$SD = \sqrt{\frac{\sum (X_i - \bar{X})^2}{n - 1}}$$

These statistics were used to compare renewable energy consumption and CO₂ emissions among the selected countries.

3.6.3 Pearson Correlation Analysis

Pearson's correlation coefficient was used to determine the strength and direction of the linear relationship between renewable energy consumption and CO₂ emissions.

The correlation coefficient was calculated as:

$$r = \frac{\sum (X - \bar{X})(Y - \bar{Y})}{\sqrt{\sum (X - \bar{X})^2 \sum (Y - \bar{Y})^2}}$$

where

- r = Pearson correlation coefficient
- X = Renewable energy consumption
- Y = CO₂ emissions

The value of (r) ranges from -1 to +1.

3.6.4 Simple Linear Regression Analysis

Simple linear regression analysis was performed to evaluate the influence of renewable energy consumption on CO₂ emissions.

The regression model used in the study was:

$$Y = \beta_0 + \beta_1 X + \epsilon$$

where

- Y = CO₂ emissions (kt)
- X = Renewable energy consumption (%)
- β_0 = Intercept
- β_1 = Regression coefficient (slope)
- ϵ = Random error

The coefficient of determination (R²) was used to assess the proportion of variation in CO₂ emissions explained by renewable energy consumption.

3.6.5 Percentage Change Analysis

Percentage change analysis was conducted to evaluate the change in renewable energy consumption and CO₂ emissions between 1990 and 2019.

The percentage change was calculated using:

$$\text{Percentage Change} = \frac{\text{Final Value} - \text{Initial Value}}{\text{Initial Value}} \times 100$$

where:

- Final Value = Value in 2019
- Initial Value = Value in 1990

This analysis was used to compare long-term changes among the selected countries.

3.7 Software Used

All statistical analyses, calculations, tables, and graphical presentations were performed using Microsoft Excel 2021.

4. Results

4.1 Trend Analysis

Trend analysis was conducted to examine the temporal changes in the share of renewable energy consumption and CO₂ emissions in China, Germany, India, Japan, and the United States during the period 1990–2019. Figures 1 and 2 illustrate the annual trends of the selected variables.

4.1.1 Renewable Energy Consumption

Figure No. 4.1 shows the trend in the share of renewable energy consumption (% of total final energy consumption) across the selected countries. India recorded the highest renewable energy share throughout the study period; however, the share gradually declined from 53.0% in 1990 to 33.5% in 2019. Similarly, China experienced a decline in the renewable energy share from 33.9% to 14.3%. It is important to note that these values represent the percentage share of renewable energy in total final energy consumption, not the absolute quantity of renewable energy consumed.

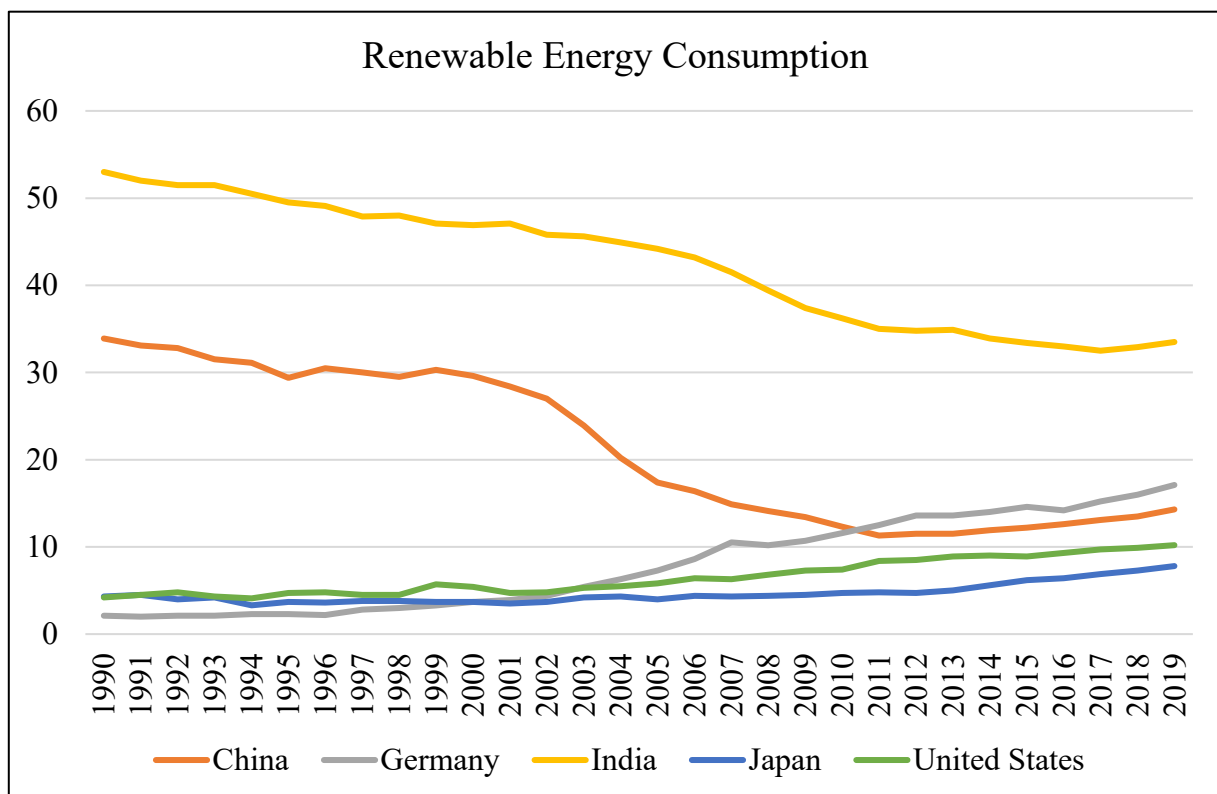


Figure No. 4.1: Renewable Energy Consumption

In contrast, Germany showed a remarkable increase in the renewable energy share, rising from 2.1% in 1990 to 17.1% in 2019, reflecting the country's successful renewable energy transition. Japan and the United States also exhibited increasing trends, with renewable energy shares increasing from 4.3%

to 7.8% and 4.2% to 10.2%, respectively. Overall, the results indicate substantial differences in renewable energy transition pathways among the selected countries over the 30-year study period.

4.1.2 CO₂ Emissions

Figure No. 4.2 presents the trend in CO₂ emissions for the selected countries. China exhibited the most significant increase in emissions, rising from 2.17 million kt in 1990 to 10.71 million kt in 2019. India also experienced a considerable increase, with emissions increasing from 0.56 million kt to 2.46 million kt during the study period.

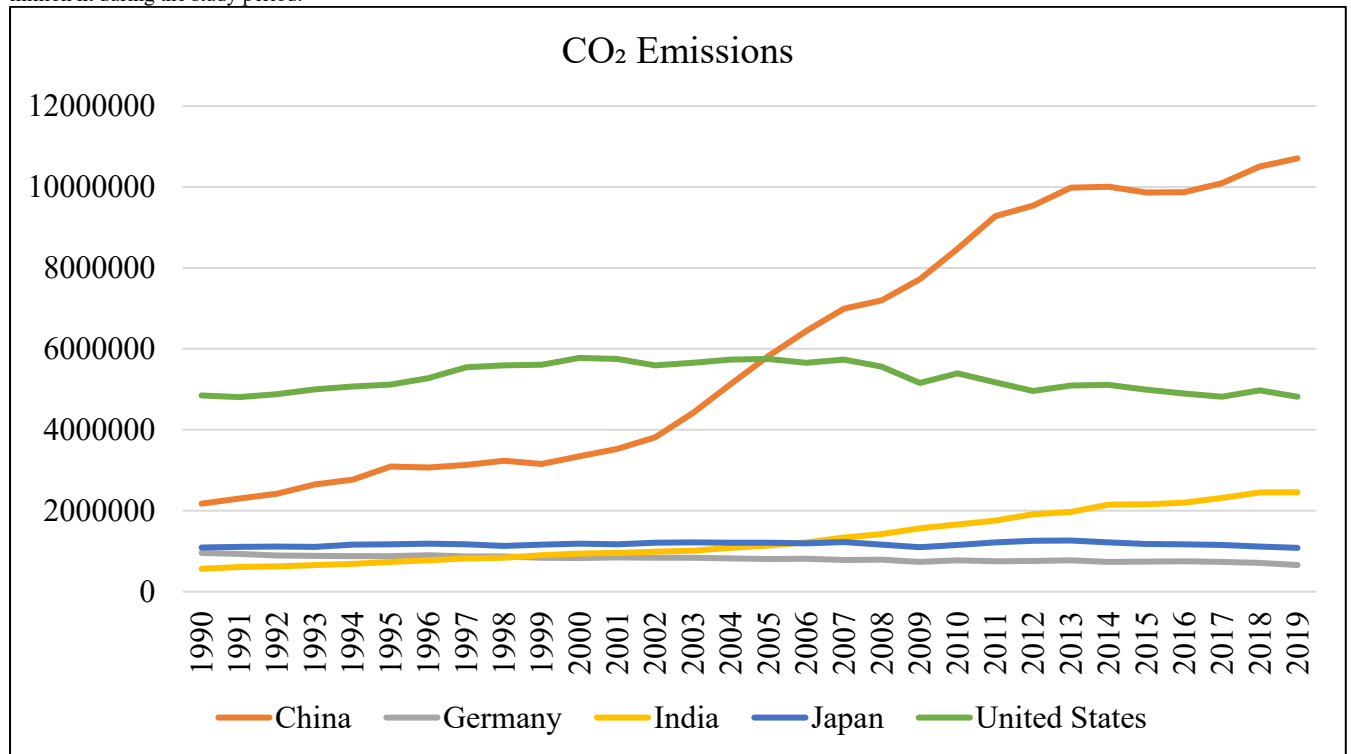


Figure No. 4.2: CO₂ Emissions

Conversely, Germany showed a continuous decline in CO₂ emissions from 955,310 kt to 657,400 kt, indicating the effectiveness of emission reduction policies and cleaner energy adoption. Japan and the United States exhibited relatively stable emission trends with slight decreases between 1990 and 2019.

The graphical analysis demonstrates that while several countries increased the share of renewable energy, the corresponding trends in CO₂ emissions differed considerably, suggesting that multiple economic and energy-related factors influence emission patterns.

4.2 Descriptive Statistics

Descriptive statistics were calculated to summarize the distribution of renewable energy share and CO₂ emissions among the selected countries.

Table No. 4.1: Descriptive Statistics of Renewable Energy Consumption (% of Total Final Energy Consumption)

Country	Mean (%)	Standard Deviation	Maximum (%)	Minimum (%)
China	21.39	8.62	33.90	11.30
Germany	7.92	5.26	17.10	2.00
India	42.54	7.05	53.00	32.50
Japan	4.64	1.17	7.80	3.30
United States	6.49	2.02	10.20	4.10

India recorded the highest average share of renewable energy consumption (42.54%), followed by China (21.39%). Germany, Japan, and the United States had comparatively lower average renewable energy shares. China exhibited the highest variability (SD = 8.62), whereas Japan showed the lowest variability (SD = 1.17), indicating relatively stable renewable energy shares over the study period.

Table No. 4.2: Descriptive Statistics of CO₂ Emissions (kt)

Country	Mean	Standard Deviation	Maximum	Minimum
China	6,024,094.31	3,113,761.43	10,707,219.73	2,173,360.00
Germany	812,234.00	71,106.97	955,310.00	657,400.02
India	1,329,424.33	620,567.32	2,456,300.05	563,580.00
Japan	1,169,219.66	47,581.82	1,262,780.03	1,081,569.95
United States	5,277,262.69	348,706.66	5,775,810.00	4,807,500.00

Among the selected countries, China recorded the highest average CO₂ emissions, followed by the United States. Germany exhibited the lowest average CO₂ emissions. China also showed the greatest variation in emissions over time, reflecting its rapid industrial and economic expansion during the study period.

4.3 Pearson Correlation Analysis

Pearson correlation analysis was conducted to examine the relationship between the share of renewable energy consumption and CO₂ emissions.

Table No. 4.3: Pearson Correlation between Renewable Energy Share and CO₂ Emissions

Country	Correlation (r)	Interpretation
China	-0.957	Very strong negative
Germany	-0.939	Very strong negative
India	-0.978	Very strong negative
Japan	-0.213	Weak negative
United States	-0.406	Moderate negative

China, Germany, and India exhibited very strong negative correlations, indicating that years with a higher renewable energy share were associated with lower CO₂ emissions in the observed data. Japan displayed only a weak negative relationship, while the United States showed a moderate negative correlation, suggesting that additional factors besides the renewable energy share likely influenced emission trends.

4.4 Simple Linear Regression Analysis

Simple linear regression analysis was performed to assess the statistical relationship between the share of renewable energy consumption (independent variable) and CO₂ emissions (dependent variable).

Table No. 4.4: Simple Linear Regression Results

Country	Regression Equation	R ²
China	CO ₂ = 13,416,040.94 – 345,633.42(RE)	0.916
Germany	CO ₂ = 912,770.51 – 12,694.00(RE)	0.882
India	CO ₂ = 4,995,467.93 – 86,178.74(RE)	0.957
Japan	CO ₂ = 1,209,439.51 – 8,661.85(RE)	0.045
United States	CO ₂ = 5,731,837.66 – 70,078.36(RE)	0.164

The regression analysis revealed that China, Germany, and India had high coefficients of determination (R² = 0.916, 0.882, and 0.957, respectively), indicating that changes in the renewable energy share were strongly associated with variations in CO₂ emissions during the study period. The negative regression coefficients indicate an inverse relationship between the renewable energy share and CO₂ emissions within the fitted models.

In contrast, Japan (R² = 0.045) and the United States (R² = 0.164) exhibited weak regression models, suggesting that the renewable energy share alone explained only a small proportion of the variation in CO₂ emissions.

Other factors such as economic growth, industrial activity, technological advancements, energy efficiency, and fossil fuel consumption may have played a more prominent role in influencing emission trends in these countries.

4.5 Percentage Change Analysis

Percentage change analysis was conducted to compare long-term changes in the share of renewable energy consumption and CO₂ emissions between 1990 and 2019.

Table No. 4.5: Percentage Change in the Share of Renewable Energy Consumption (1990–2019)

Country	Percentage Change (%)
China	-57.82
Germany	714.29
India	-36.79
Japan	81.40
United States	142.86

Germany experienced the largest increase in the share of renewable energy consumption, with an increase of 714.29%, followed by the United States (142.86%) and Japan (81.40%). In contrast, China and India showed decreases of 57.82% and 36.79%, respectively, in the share of renewable energy consumption over the study period. These findings indicate changes in the contribution of renewable energy to total final energy consumption rather than changes in the absolute amount of renewable energy consumed.

Table 4.6: No. Percentage Change in CO₂ Emissions (1990–2019)

Country	Percentage Change (%)
China	392.66
Germany	-31.18
India	335.84
Japan	-0.82
United States	-0.55

China recorded the largest increase in CO₂ emissions (392.66%), followed by India (335.84%). Germany achieved a substantial reduction in CO₂ emissions (31.18%), while Japan and the United States exhibited only marginal decreases of 0.82% and 0.55%, respectively.

Overall, the results suggest that countries such as Germany, which substantially increased the share of renewable energy consumption, also experienced declining CO₂ emissions over the study period. Conversely, China and India recorded significant increases in CO₂ emissions while the share of renewable energy in total final energy consumption declined. Japan and the United States showed relatively small changes in CO₂ emissions despite moderate increases in the renewable energy share, indicating that factors beyond renewable energy share also influence national emission trajectories. This highlights the importance of considering broader economic, technological, and energy-system characteristics when interpreting the relationship between renewable energy and CO₂ emissions.

5. Discussion

The present study examined the relationship between the share of renewable energy consumption and CO₂ emissions in China, Germany, India, Japan, and the United States over the period 1990–2019 using trend analysis, descriptive statistics, Pearson correlation, simple linear regression, and percentage change analysis. The findings indicate substantial differences among the selected countries regarding renewable energy transition and CO₂ emission patterns.

Trend analysis showed that Germany, Japan, and the United States experienced an increase in the share of renewable energy consumption, whereas China and India recorded a decline in the renewable energy share over the study period. It is important to note that the renewable energy indicator used in this study represents the percentage of total final energy consumption, rather than the absolute amount of renewable energy consumed. Therefore, a declining renewable energy share does not necessarily indicate reduced renewable energy production; instead, it reflects a reduction in the proportion of renewable energy relative to total final energy consumption. Germany's substantial increase in renewable energy share is consistent with its long-term renewable

energy policies, including the *Energiewende*, which encouraged investment in wind, solar, and other renewable energy technologies (IRENA, 2023).

The trend analysis of CO₂ emissions demonstrated contrasting emission trajectories among the selected countries. China and India exhibited substantial increases in CO₂ emissions, while Germany experienced a notable decline. Japan and the United States showed relatively stable emissions with slight decreases. These findings are generally consistent with the International Energy Agency (2021), which reported that rapidly industrializing economies continue to experience increasing energy demand and carbon emissions, whereas countries implementing long-term clean energy and energy efficiency policies have achieved greater emission reductions.

The descriptive statistics revealed considerable variation among the selected countries. India recorded the highest average renewable energy share (42.54%), while China exhibited the highest average CO₂ emissions. These differences reflect variations in energy structure, industrial development, and economic growth across countries. Similar cross-country variations have been reported by Shafiei and Salim (2014), who found that the influence of renewable energy on environmental quality differs according to national economic and energy characteristics.

Pearson correlation analysis indicated very strong negative relationships between renewable energy share and CO₂ emissions in China ($r = -0.957$), Germany ($r = -0.939$), and India ($r = -0.978$). These findings suggest that years with a higher renewable energy share were associated with lower CO₂ emissions within the observed data. Similar negative associations have been reported by Zoundi (2017), who concluded that renewable energy contributes to environmental improvement by reducing carbon emissions. Likewise, Perone (2024) reported that renewable energy expansion is associated with long-term reductions in CO₂ emissions among OECD countries.

The regression analysis further supported these observations. High coefficients of determination were obtained for China ($R^2 = 0.916$), Germany ($R^2 = 0.882$), and India ($R^2 = 0.957$), indicating that the fitted linear models explained a large proportion of the variation in CO₂ emissions during the study period. However, Japan ($R^2 = 0.045$) and the United States ($R^2 = 0.164$) exhibited relatively weak linear relationships, suggesting that factors beyond renewable energy share likely contributed to national emission trends. These findings agree with Wagner (2021), who emphasized that economic growth, industrial production, technological progress, and energy efficiency improvements also influence CO₂ emissions and should be considered when evaluating environmental performance.

Percentage change analysis highlighted substantial differences among the selected countries. Germany recorded the largest increase in renewable energy share (714.29%) and simultaneously reduced CO₂ emissions by 31.18%. In contrast, China and India experienced large increases in CO₂ emissions while the renewable energy share declined over the study period. Japan and the United States exhibited moderate increases in renewable energy share but only slight decreases in CO₂ emissions. These results suggest that increasing the renewable energy share alone may not fully explain national emission trajectories, particularly in countries with rapidly expanding economies or high energy demand.

Overall, the findings indicate that the relationship between renewable energy share and CO₂ emissions varies among countries depending on economic development, industrialization, energy policies, and technological advancement. Therefore, renewable energy expansion should be complemented by improvements in energy efficiency, cleaner industrial technologies, and effective environmental policies to achieve substantial reductions in CO₂ emissions.

6. Conclusion

This study conducted a comparative statistical analysis of the relationship between the share of renewable energy consumption and CO₂ emissions in China, Germany, India, Japan, and the United States during the period 1990–2019 using secondary data obtained from the World Bank.

Trend analysis showed that Germany, Japan, and the United States increased the share of renewable energy in total final energy consumption, whereas China and India experienced declining renewable energy shares. CO₂ emissions increased considerably in China and India, declined substantially in Germany, and remained relatively stable in Japan and the United States.

Descriptive statistics demonstrated considerable differences in renewable energy shares and CO₂ emission levels among the selected countries. Correlation analysis revealed very strong negative relationships between renewable energy share and CO₂ emissions in China, Germany, and India, while weaker relationships were observed for Japan and the United States. Similarly, regression analysis indicated that renewable energy share explained a substantial proportion of CO₂ emission variation in China, Germany, and India but had relatively limited explanatory power in Japan and the United States.

Percentage change analysis further highlighted Germany's significant renewable energy transition and reduction in CO₂ emissions, whereas China and India recorded substantial increases in emissions despite changes in renewable energy share. These findings emphasize that national emission patterns are influenced by multiple interacting factors, including economic growth, industrial activity, technological development, and energy policies.

The study demonstrates that comparative statistical analysis using publicly available international datasets provides valuable insights into long-term energy and environmental trends. Future studies may incorporate additional explanatory variables such as GDP, population growth, fossil fuel consumption, electricity generation mix, and energy intensity, as well as employ panel data or time-series econometric techniques to provide a more comprehensive understanding of the relationship between renewable energy and CO₂ emissions.

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