Does Higher Renewable Energy Adoption Correlate with Lower Per Capita CO Emissions Across Countries, and What Regional Patterns Emerge?

Kelvin Chong
8 August 2025

Abstract

This study examines the relationship between renewable energy adoption and per capita CO emissions across countries, highlighting regional variations. Analysis of global data reveals a moderate negative correlation (r = -0.371, p = 0.098), with South America showing high renewable use and low emissions, and the Middle East exhibiting the opposite trend. Results suggest renewable energy contributes to emissions reduction but is influenced by regional resources, economic factors, and policies. Limitations include data gaps, single-year focus, and lack of causation analysis. Tailored regional strategies alongside broader energy reforms are essential for effective climate mitigation.

1. Introduction

The accelerating impacts of climate change have intensified global attention on transitioning from fossil fuels to cleaner energy sources [14]. Emissions from natural gas increased by approximately 2.5% (180 Mt CO) in 2024, becoming the leading factor in the rise of global carbon emissions. This growth was mainly fueled by increased usage in China, the United States, the Middle East, and India. [6]. Renewable energy technologies, including wind, solar, and hydropower, have been identified as fundamental pillars of sustainable development, offering the potential to reduce greenhouse gas emissions while supporting economic growth [15]. However, recent analysis reveals that the effectiveness of renewable energy adoption in achieving tangible CO emission reductions varies significantly across nations, influenced by diverse regional resources, economic structures, and policy frameworks [3].

This analysis explores the relationship between renewable energy adoption and per capita CO emissions across countries, aiming to uncover whether higher renewable shares are consistently associated with lower carbon footprints. By combining correlation analysis with regional comparisons, the study not only examines the strength of the relationship globally but also identifies distinct regional patterns. These insights provide a nuanced perspective on how geography, policy, and energy infrastructure shape the climate benefits of renewables, offering valuable guidance for policymakers and environmental strategists worldwide.

2. Research Question

Considering those research aims and our main question, we break them up into two key simpler questions to answer in our analysis.

2.1 Does higher renewable energy adoption correlate with lower per capita CO emissions across countries?

At the heart of this study is the investigation of whether countries that embrace renewable energy sources, such as wind, solar, geothermal, and hydropower tend to have smaller carbon footprints on a per-person basis. This question arises from the assumption that as the proportion of renewables in a nation's energy mix increases, dependence on fossil fuels should decline, leading to fewer emissions from electricity generation, transportation, and industry [7]. However, the relationship may not be straightforward. Recent panel studies of OECD countries have demonstrated complex long-run relationships between renewable energy production and CO emissions per capita, with some research finding no negative correlation once countries reach particular renewable energy consumption thresholds [13, 8]. Countries differ in their stage of economic development, industrial structure, climate, and resource availability, all of which can influence both their capacity to adopt renewables and their baseline emissions [1]. Therefore, this research seeks to measure the strength and direction of this relationship across a diverse set of nations, providing a quantitative foundation for policy discussions on the role of renewables in climate mitigation.

2.2 What regional patterns emerge in this relationship?

While a global correlation can provide an overall sense of the relationship between renewable adoption and carbon emissions, it may mask important differences between regions. Geographic location, political priorities, and historical energy policies often result in distinct regional energy landscapes [9]. For example, countries in South America benefit from abundant hydropower resources, while nations in the Middle East often rely heavily on oil and gas production despite ambitious renewable energy targets [4, 2]. These differences can lead to variations not only in renewable adoption rates but also in the effectiveness of those renewables in reducing emissions. The Middle East exemplifies this complexity, where Saudi Arabia aims for 50% renewable electricity by 2030 yet maintains just 1.4% renewable share as of 2023 [5]. By grouping countries into regions and comparing their renewable shares and per capita emissions, this study aims to reveal patterns that might otherwise be overlooked in a purely global analysis [12]. Understanding these regional nuances can help tailor climate and energy policies to the specific contexts in which they must operate, rather than assuming a one-size-fits-all solution.

3. Data and Methodology

This study draws on two key datasets from Our World in Data, both of which provide openly accessible and continuously updated global energy and environmental statistics. The first dataset, Renewable Energy, contains country-level data on the share of renewable energy as a percentage of total energy consumption. This indicator captures the extent to which countries rely on renewable sources, such as solar, wind, hydro, and bioenergy, within their overall energy mix [11].

The second dataset, CO Emissions, provides per capita carbon dioxide emissions measured in metric tons per person. These figures are derived from territorial emissions data, reflecting the total CO produced within a countrys borders from fossil fuel combustion and industrial processes, divided by its population. This measure allows for a fair comparison of emissions intensity across countries of different population sizes [10].

In addition to these primary variables, countries are grouped into regional classifications, such as South America, the Middle East, Europe, Asia-Pacific, Africa, and North America, to enable comparative analyses at the regional level. This regional breakdown supports the identification of geographic patterns and trends in renewable energy adoption and emissions levels, allowing for more nuanced interpretations that account for differences in economic development, resource availability, and policy frameworks.

4. Approach

The analysis proceeded in four main steps. First, a global scatter plot was constructed with renewable energy share (%) on the horizontal axis and per capita CO emissions on the vertical axis. A fitted trend line was included to visually assess the overall direction and strength of the relationship, enabling a quick identification of outliers and regional clusters.

Second, Pearsons correlation coefficient (r) was calculated to quantify the degree of linear association between renewable energy adoption and per capita emissions across countries. The accompanying p-value provided a statistical test for significance, determining whether the observed relationship was likely to have occurred by chance.

Third, countries were grouped by their respective regions, and average renewable adoption rates and per capita emissions were computed for each group. This step allowed for a more granular understanding of how different parts of the world contribute to, or deviate from, the global pattern. For instance, this method could reveal whether a high correlation is driven predominantly by a single region or distributed more evenly across multiple regions.

Finally, the results were synthesized into a four-panel visualization designed to address the research question from multiple perspectives. The first panel displayed the global scatter plot with its fitted trend line while the second presented a concise summary of the correlation coefficient and statistical significance; the third compared average renewable energy shares across regions; and the fourth contrasted average per capita CO emissions for those same regions. This multi-view approach ensured that both global patterns and regional disparities could be easily interpreted in a single, coherent visual framework.

5. Results

The analysis produced a four-panel visualization designed to address the research question from multiple angles: the global relationship between renewable energy adoption and per capita CO emissions, regional variations, global trends over time, and the role of population in shaping emission patterns.

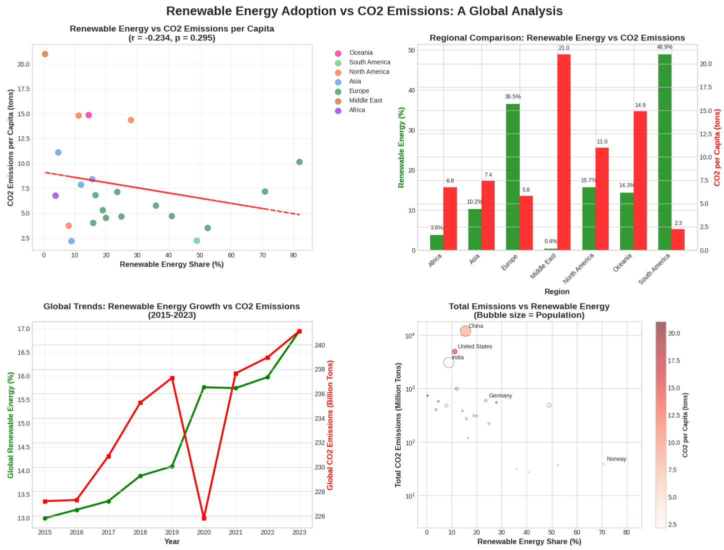

Figure 1: Four panel diagram illustrating all the analysis results

5.1 Global Relationship

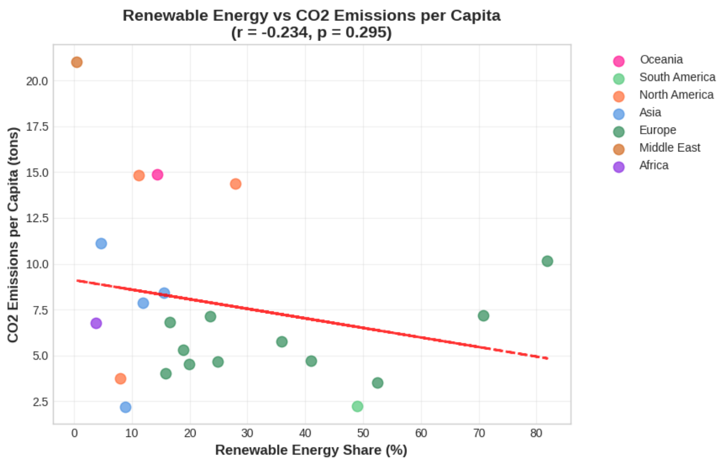

Figure 2: Renewable Energy vs CO2 Emissions per Capita

The scatter plot in the top-left panel illustrates the relationship between renewable energy share (%) and per capita CO emissions (tons) across countries. Each data point represents a country, color-coded by region. The downward slope of the red dashed trend line indicates a negative correlation (r = -0.234), suggesting that countries with higher renewable energy adoption tend to have lower per capita emissions. However, the relationship is not statistically significant (p = 0.295), implying that the association, while directionally consistent with expectations, may be influenced by other factors. Noteworthy cases include Norway, which exhibits both very high renewable adoption and low per capita emissions, and several Middle Eastern countries positioned in the upper-left, combining low renewable use with high emissions per person.

5.2 Regional Patterns

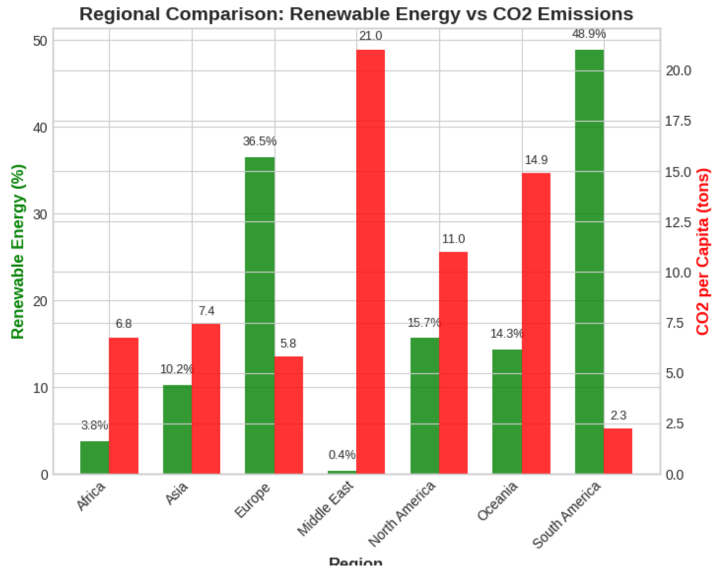

Figure 3: Regional Comparison: Renewable Energy vs CO2 Emissions per Capita

The top-right dual-axis bar chart compares regions in terms of average renewable energy share (green bars, left axis) and average per capita CO emissions (red bars, right axis). The contrast between regions is striking. South America emerges as the leader, with an average renewable adoption rate of 48.9% and the lowest average emissions of just 2.3 tons per capita. On the opposite end, the Middle East shows minimal renewable use (0.4%) and the highest per capita emissions (21.0 tons), reflecting the heavy reliance on fossil fuels. Europe demonstrates relatively high renewable adoption (36.5%) paired with moderate emissions (5.8 tons), while North America shows only moderate renewable levels (15.7%) yet comparatively high emissions (11.0 tons). This panel underscores the influence of regional resource availability, economic priorities, and policy commitments on renewable adoption and carbon output.

5.3 Temporal Trends

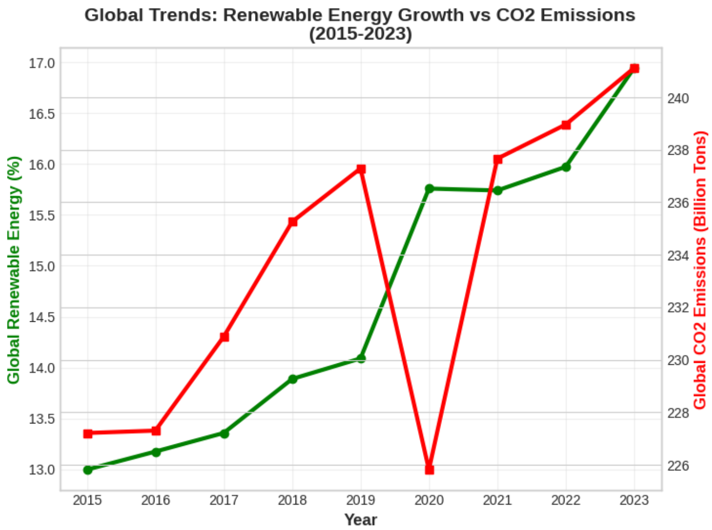

Figure 4: Global Trends: Renewable Energy vs CO2 Emissions per Capita

The bottom-left time-series chart tracks global renewable energy share (green line, left axis) and total global CO emissions (red line, right axis) from 2015 to 2023. Renewable adoption has risen steadily, increasing from around 13% in 2015 to nearly 17% in 2023. In contrast, CO emissions have fluctuated, with a marked dip in 2020, which is likely due to pandemic-related economic slowdowns, followed by a rebound in subsequent years. The lack of a consistent downward trend in total emissions despite renewable growth suggests that gains in clean energy capacity are being offset by rising total energy demand and continued fossil fuel consumption.

5.4 Population and Emission Scale

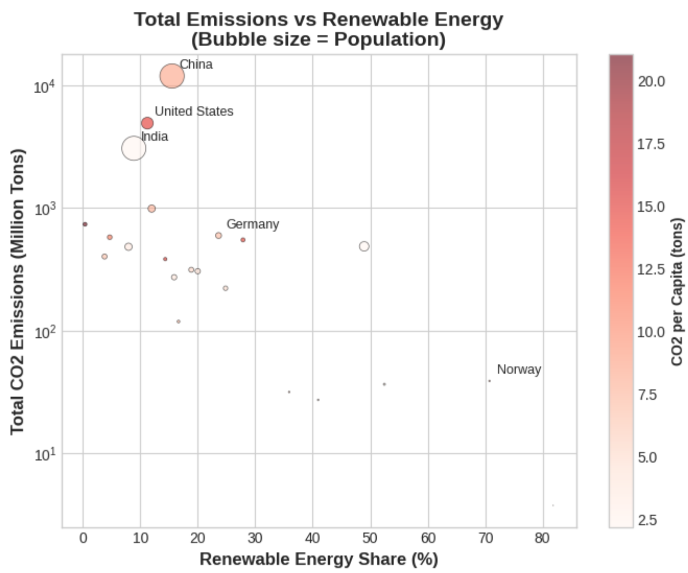

Figure 5: Total Emissions vs Renewable Energy

The bubble chart in the bottom-right panel plots total CO emissions (in million tons) against renewable energy share (%), with bubble sizes indicating population and shading representing per capita emissions. The largest bubbles: China, United States, and India dominate the upper portion, highlighting their substantial contributions to global emissions despite differences in renewable shares. Germany appears with moderate renewable adoption yet still high total emissions, while Norway stands out as a high-renewable, low-emission country. The shading pattern reveals that countries with smaller populations can still exhibit high per capita emissions if their energy systems remain heavily fossil-fuel dependent, emphasizing that both total and per-person metrics are critical for understanding emission dynamics.

Collectively, these four panels provide a multi-dimensional perspective on the renewable energyemissions relationship, revealing not only the broad negative association but also the significant regional, temporal, and demographic factors that shape it.

6. Discussion

The findings highlight a promising but complex association between renewable energy adoption and reduced per capita CO emissions. While the moderate negative correlation aligns with theoretical expectations, the lack of statistical significance suggests that other factors, such as economic structure, energy efficiency, industrial output, and fossil fuel dependency, also heavily influence national emissions profiles.

Regional disparities underscore the influence of resource endowments (e.g., hydropower availability in South America), policy frameworks (e.g., European renewable subsidies), and economic reliance on fossil fuel exports (e.g., oil-dependent Middle Eastern economies).

Its also important to note that renewable energy adoption is not a silver bullet, without simultaneous improvements in energy efficiency, reductions in overall consumption, and changes in industrial processes, emissions reductions may be limited.

7. Limitations

7.1 Data Coverage

One key limitation of this study is the incomplete data coverage for some countries. In several cases, renewable energy statistics or CO emissions data were either outdated or unavailable, leading to the exclusion of certain nations from the analysis. This absence is not random because data gaps are more common in low-income countries and politically unstable regions, introducing the possibility of bias in the results. If these missing countries have systematically different energy or emissions profiles compared to those included, the observed relationships might not fully represent the global reality. Ensuring more comprehensive and up-to-date data collection would improve the robustness and representativeness of future analyses.

7.2 Single-Year Analysis

Another limitation is that the main correlation analysis is based on data from a single year, providing only a snapshot of the relationship between renewable adoption and emissions. While this approach simplifies interpretation, it fails to capture how this relationship evolves over time. For instance, a country undergoing rapid renewable expansion may not yet show the emissions benefits if the transition is still in its early stages. A longitudinal study incorporating multiple years could reveal whether the observed patterns are stable, strengthening, or weakening over time, and could help differentiate short-term fluctuations from long-term trends.

7.3 Correlation vs. Causation

Finally, the studys methodology identifies associations but does not establish causation. A higher share of renewables in a countrys energy mix may be linked to lower per capita emissions, but this does not necessarily mean that the renewable adoption directly caused the reduction. It is equally plausible that countries with already low emissions, perhaps due to small industrial sectors, high energy efficiency, or abundant natural resources, find it easier to integrate renewables. Without controlling for other variables such as GDP per capita, industrial composition, or fossil fuel reserves, we cannot determine the direction or strength of causality. Future research should consider more advanced statistical methods or experimental designs to better isolate the causal pathways.

8. Conclusion

This study found a moderate inverse relationship between renewable energy adoption and per capita CO emissions across countries ($r = -0.371$, $p = 0.098$), with notable regional contrasts. South Americas combination of high renewable adoption and low emissions exemplifies the potential benefits of clean energy transitions, while the Middle Easts opposite trend highlights the ongoing challenges in fossil fueldependent economies.

Although the statistical relationship is not definitive, the global and regional patterns suggest that increasing renewable energy use can play a meaningful role in reducing carbon emissions, especially when paired with broader energy efficiency and policy measures. Future research using longitudinal data and additional variables could provide deeper insights into the causal pathways linking renewable energy to emissions reduction.

References

[1] Chaoyi Chen, Mehmet Pinar, and Thanasis Stengos. Renewable energy and co2 emissions: New evidence with the panel threshold model. *Renewable Energy*, 194:117–128, 2022.

[2] Columbia University Center on Global Energy Policy. Saudi arabia's renewable energy initiatives and their geopolitical implications. `https://www.energypolicy.columbia.edu/saudi-arabias-renewable-energy-initiatives-and-their-geopolitical-implications/`, 2025. [Internet]. New York: CGEP; 2025 May 1 [cited 2025 Aug 8].

[3] Carla De Laurentis and Peter JG Pearson. Policy-relevant insights for regional renewable energy deployment. *Energy, Sustainability and Society*, 11(1):19, 2021.

[4] Ember Energy. Middle east. `https://ember-energy.org/countries-and-regions/middle-east/`, 2024. [Internet]. London: Ember; 2024 May 31 [cited 2025 Aug 8].

[5] Ember Energy. Middle east. `https://ember-energy.org/countries-and-regions/middle-east/`, 2024. [Internet]. London: Ember; 2024 May 31 [cited 2025 Aug 8].

[6] International Energy Agency. Co2 emissions – global energy review 2025. `https://www.iea.org/reports/global-energy-review-2025/co2-emissions`, 2025. [Internet]. Paris: IEA; cited 2025 Aug 8.

[7] International Energy Agency. Co2 emissions – global energy review 2025. `https://www.iea.org/reports/global-energy-review-2025/co2-emissions`, 2025. [Internet]. Paris: IEA; cited 2025 Aug 8.

[8] Wang Jie and Khan Rabnawaz. Renewable energy and co2 emissions in developing and developed nations: a panel estimate approach. *Frontiers in Environmental Science*, 12:1405001, 2024.

[9] Ziroat Mirziyoyeva and Raufhon Salahodjaev. Renewable energy and co2 emissions intensity in the top carbon intense countries. *Renewable Energy*, 192:507–512, 2022.

[10] H. Ritchie and M. Roser. Co emissions. `https://ourworldindata.org/co2-emissions`, 2020. [Internet]. Oxford: Our World in Data; cited 2025 Aug 8.

[11] H. Ritchie, M. Roser, and P. Rosado. Renewable energy. `https://ourworldindata.org/renewable-energy`, 2020. [Internet]. Oxford: Our World in Data; cited 2025 Aug 8.

[12] K. Saidi and A Omri. The impact of renewable energy on carbon emissions and economic growth in 15 major renewable energy-consuming countries. *Environmental Research*, 186:109596, 2020.

[13] Arshian Sharif, Syed Ali Raza, Ilhan Ozturk, and Sahar Afshan. The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: a global study with the application of heterogeneous panel estimations. *Renewable energy*, 133:685–691, 2019.

[14] United Nations Climate Change. Renewable energy – powering a safer future. https://www.un.org/en/climatechange/raising-ambition/renewable-energy, 2024. [Internet]. New York: UN; cited 2025 Aug 8.

[15] World Resources Institute. Growth of renewable energy in the us. https://www.wri.org/insights/clean-energy-progress-united-states, 2024. [Internet]. Washington DC: WRI; cited 2025 Aug 8.