“The Role of Non-fossil-based Energy Sources in Reducing CO_2 Emissions in Europe (1965–2023)”

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Abstract

This study analyzes data from the **Our World in Data Energy Datasets** to investigate the impact of non-fossil-based energy sources—solar, wind, hydropower, bioenergy, other renewables, and nuclear energy—on CO_2 emissions in Europe. The analysis begins with cleaning, merging, and filtering global data to focus on continents, followed by visualizations of global population distributions, CO_2 emissions, and CO_2 emissions per capita. The study then narrows its focus to Europe, examining the evolution of fossil-based and non-fossil-based energy consumption and their relationship with CO_2 emissions from 1965 to 2023. A regression analysis is performed on data from 2000–2023 to reflect the increased adoption of alternative energy sources. This quantifies the relationship between individual energy sources and CO_2 emissions. Results suggest that **solar, wind, and bioenergy consumption** have had the most significant impact in reducing emissions, while other renewables show no measurable effect, and nuclear energy exhibits only a weak impact. As this is a miniproject, the findings provide preliminary insights and may not fully represent the real-world contributions of these energy sources.

Motivation

The urgent need to mitigate climate change has driven significant global investment in non-fossil-based energy technologies. These include renewable sources such as solar, wind, hydropower, and bioenergy, as well as non-renewable but low-carbon options like nuclear energy. Europe has positioned itself as a leader in this energy transition, pursuing ambitious climate targets and adopting a diverse range of alternative energy sources. The relationship between the growth of these energy sources and the reduction of CO_2 emissions is complex.

Understanding how different energy sources contribute to reducing CO_2 emissions is scientifically intriguing and provides valuable context for assessing the progress of energy transitions in Europe. By examining the evolution of energy consumption and emissions over time, this project highlights the historical roles of various energy sources. While the findings may not directly influence policy decisions, they contribute to a deeper understanding of the dynamics of energy transitions and their impact on emissions. This, in turn, can foster informed discussions on sustainable energy strategies and the broader implications of transitioning to a low-carbon economy.

Dataset(s)

I used 2 datasets from the **Our World in Data** platform:

1. Energy Data

This dataset focuses on global and regional energy production, consumption, and trends over time. It has 130 features including: Countries, Primary Energy consumption, Electricity Generation and Global Energy Trends.

2. CO_2 and Greenhouse Gas Emissions

This dataset focuses on emissions trends, their sources across the globe, and trends overtime. It has 79 features including: Countries, CO2 Emissions, CO2 Emission per capita and Green House Gas Emissions

Data Preparation and Cleaning

To prepare the data for analysis, I worked with 2 datasets: **The first** containing **energy-related information** (e.g., fossil fuel and renewable energy consumption) and **the second** with **CO_2 emissions data** (e.g., total CO_2 emissions, CO_2 per capita, and greenhouse gas emissions). The key steps were as follows:

1. Filtering Relevant Features: I selected only the features required for the analysis, including energy consumption by source (e.g., fossil fuels, renewables, and nuclear) and CO_2 emissions indicators.

2. Ensuring Consistent Data: Before merging the datasets, I verified that the same countries existed in both datasets to ensure compatibility.

3. Merging Datasets: I merged the two datasets based on matching countries and years, ensuring that the combined dataset included all relevant energy and emissions data for analysis.

4. Filtering by Continents: Since the analysis focused on continents, I filtered the merged dataset to include only continent-level data.

5. Handling Missing Data: For some steps, such as when analyzing non-fossil-based energy sources in Europe, I replaced missing values with 0 rather than dropping them. This approach preserved valuable information that would otherwise have been lost.

Research Question(s)

1. How do CO_2 emissions per capita differ across continents, and what does this reveal about the relationship between population and emissions?

2. How have non-fossil-based energy consumption trends (e.g., renewables, nuclear) evolved in Europe from 1965 to 2023?

3. What role have renewable and low-carbon energy sources played in reducing CO_2 emissions in Europe during the period of increased investments (2000–2023)?

Methods

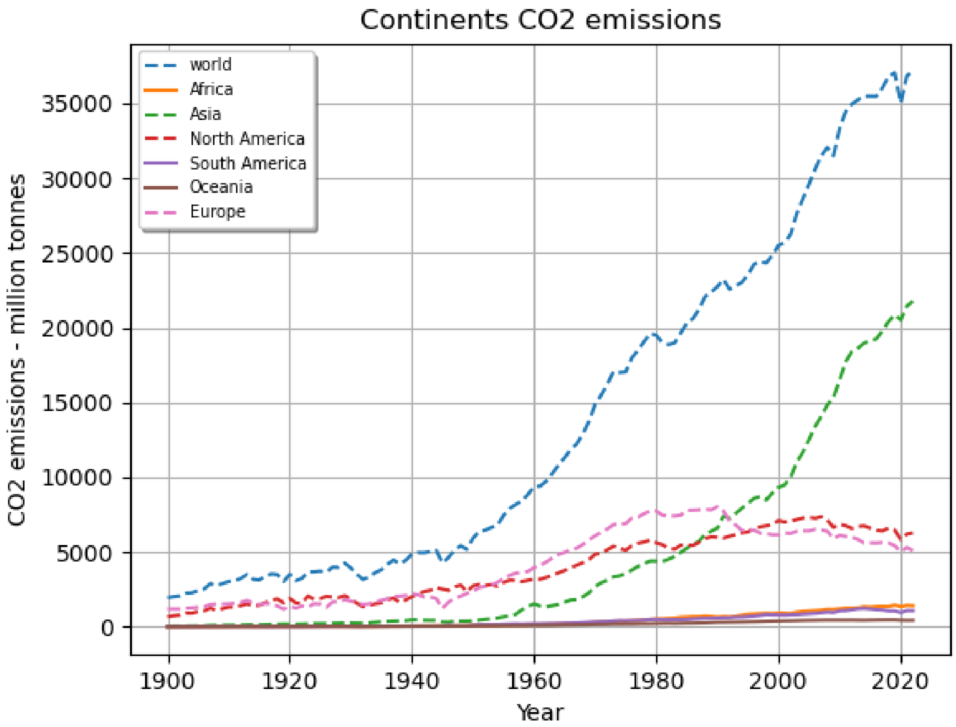
1. Data Visualization: For CO_2 Emissions and Population I used bar charts and line plots to explore global trends in CO_2 emissions and per capita emissions across continents, highlighting regional differences and temporal changes.

2. Data Visualization: For Energy and CO_2 Trends in Europe I created line plots to illustrate the evolution of fossil-based, renewable, and low-carbon energy consumption alongside CO_2 emissions in Europe from 1965 to 2023.

3. Correlation Analysis: I conducted a correlation analysis on European data from 2000 to 2023 to identify relationships between CO_2 emissions and specific energy sources (e.g., solar, wind, bioenergy, and nuclear).

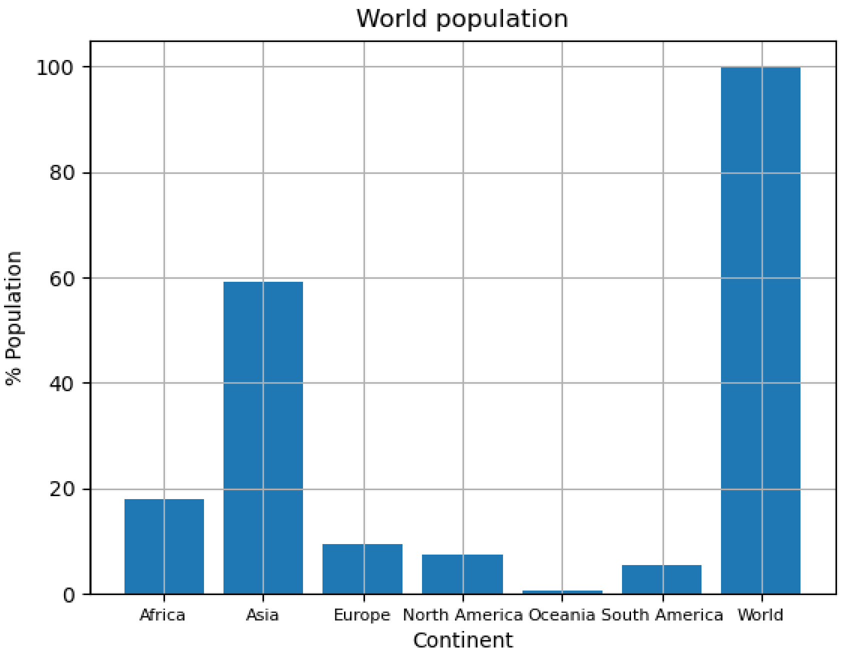
4. Linear Regression: I performed a linear regression analysis on European data from 2000 to 2023 to quantify the contributions of non-fossil-based energy sources to emissions reductions, focusing on the period of increased investment in alternative energy.

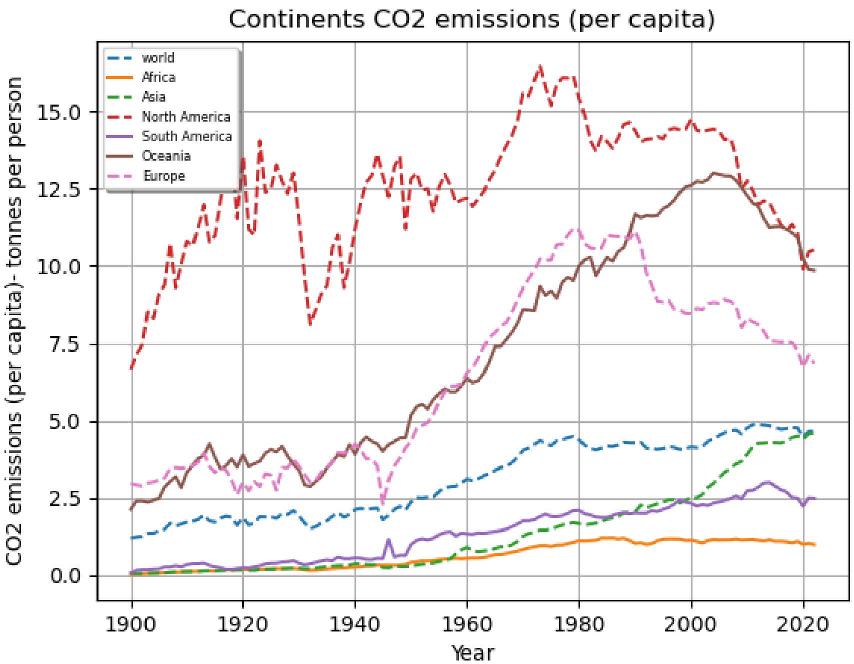
Findings - **Continental CO_2 Emissions Trends**



The analysis shows clear differences in CO_2 emissions across continents. Asia leads as the largest contributor, driven by its rapid industrial growth and large population. North America and Europe follow, reflecting their long history of industrial activity and energy use. On the other hand, Africa and South America, as less developed regions, have much lower emissions, while Oceania also has minimal emissions probably due to its smaller population.

Findings - CO_2 Emissions per capita Trends



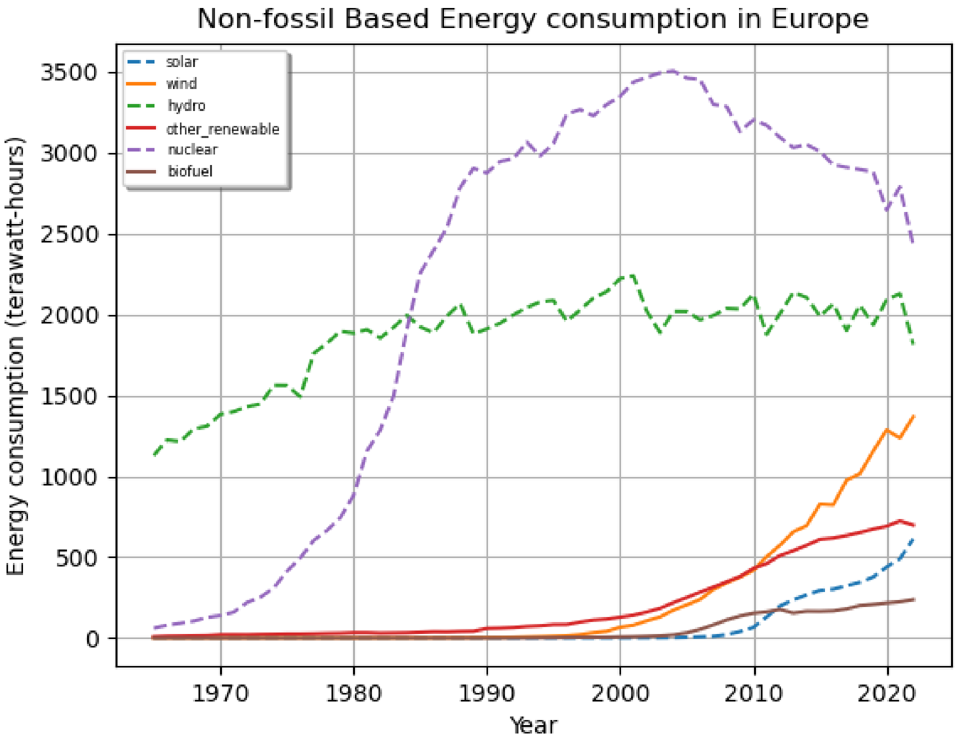


A bar graph of population distribution shows Asia as the most populous continent (59%), followed by Africa (18%), Europe (9%), North America (7.5%), South America (5.4%), and Oceania (0.56%).

The line graph of CO_2 emissions per capita highlights North America, Europe, and Oceania as the highest emitters, reflecting their high energy consumption and industrial activity relative to smaller populations. Europe shows a notable decline starting around 1990, with significant reductions by 2023. Asia follows with rising per capita emissions due to industrialization, while South America and Africa remain the lowest emitters.

Findings

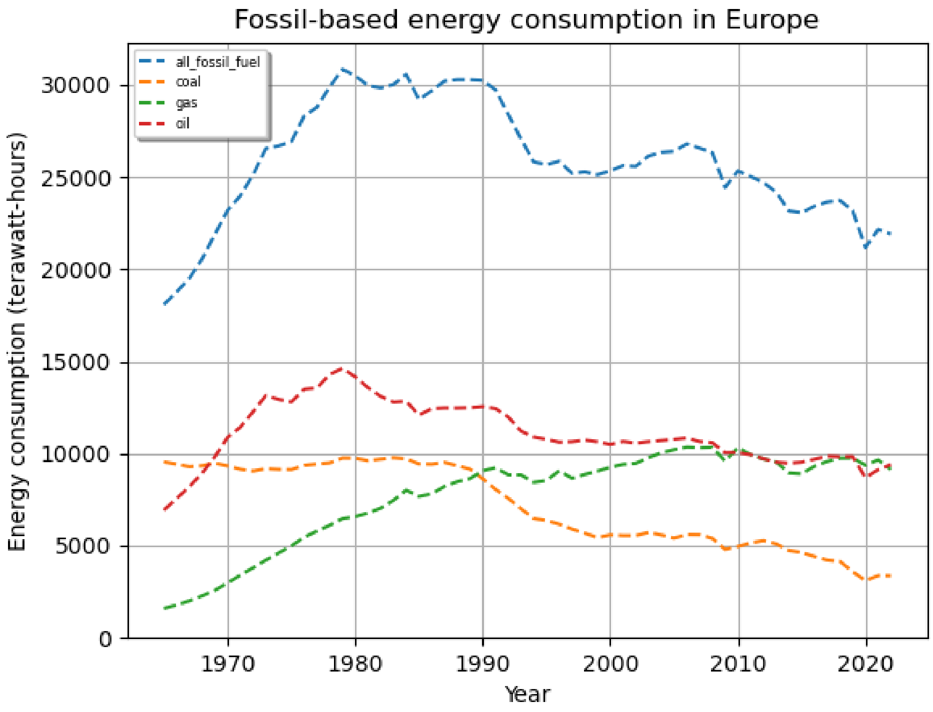
Evolution of Non-Fossil-Based Energy Consumption in Europe



Non-fossil-based energy consumption in Europe shows distinct trends. Nuclear energy increased steadily from 1965 until the early 2000s, after which it began to decline. Hydropower grew until around 1985 and has remained stable since. Wind energy was negligible until the late 1990s, after which it steadily increased. Other renewables, such as geothermal and tidal energy, saw slow growth from the 1980s, with a steeper rise beginning around 2000. Solar energy was nearly absent until 2005 but has since grown significantly. Biofuels were largely unused until 2004, after which they have shown a slow but steady rise.

Findings

Evolution of Fossil-Based Energy Consumption in Europe

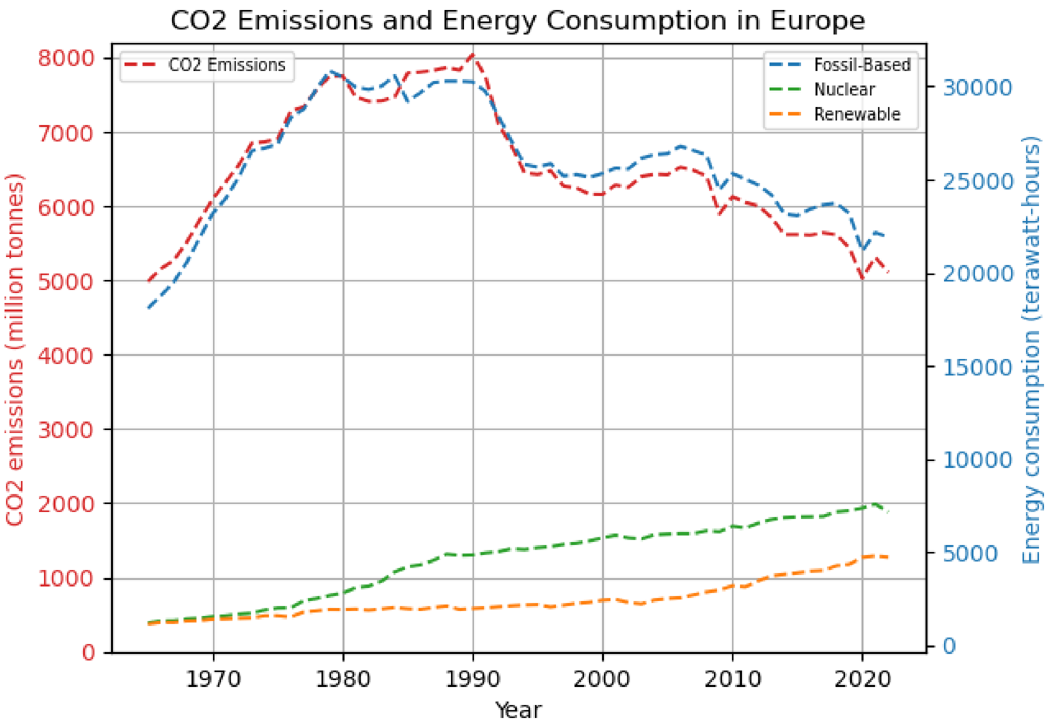


This plot shows that coal consumption remained steady from 1965 until the late 1980s, after which it declined. Oil consumption rose until 1979, then gradually decreased, while gas consumption increased until 1990 and has since remained constant.

Overall, total fossil-based energy consumption (all_fossil _fuel) increased until the late 1970s, stabilized through the early 1990s, and has been steadily decreasing. This decline aligns with the rise in alternative energy sources, such as wind, solar, and other renewables, seen in the previous analysis.

Findings

CO_2 Emissions and Energy Sources in Europe (1965–2023)



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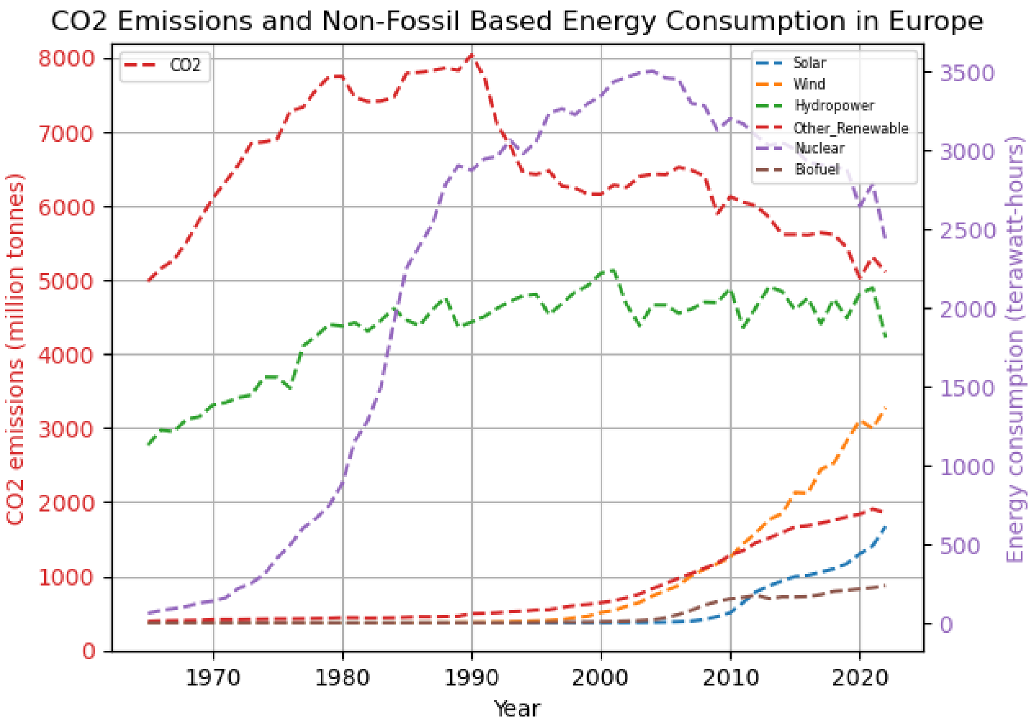
Findings

CO_2 Emissions vs. Renewable and Nuclear Energy Consumption



The line plot shows that CO_2 emissions in Europe began declining steadily after 1990, coinciding with the rise of renewable energy and the earlier growth of nuclear energy. Renewables like wind and solar saw rapid growth from the late 1990s onward, aligning with a sharper drop in emissions. Nuclear energy, which increased from the 1970s, contributed to early reductions but has since stabilized or declined. These trends suggest that the growth of non-fossil energy sources has played a key role in reducing CO_2 emissions.

Findings

CO_2 Emissions vs. Renewable and Nuclear Energy Consumption

	co2
fossil_fuel_consumption	0.9936279594088124
coal_consumption	0.949935300071948
gas_consumption	0.6365608330844592
oil_consumption	0.929900144677865
solar_consumption	-0.9496452552460936
wind_consumption	-0.9398090058271628
hydro_consumption	0.08411036533307521
biofuel_consumption	-0.8529335746187949
other_renewable_consumption	-0.8873943900243113
nuclear_consumption	0.9525347836733781
co2	1.0

The correlation analysis highlights strong relationships between CO_2 emissions and energy sources in Europe:

• Fossil-Based Energy: CO_2 emissions are strongly correlated with fossil fuel consumption (0.99), including coal (0.95), oil (0.93), and gas (0.64), suggesting these are major drivers of emissions.

• Renewable Energy: Negative correlations with solar (-0.95), wind (-0.94), biofuel (-0.85), and other renewables (-0.89) suggest their growth is associated with emissions reductions.

• Hydropower: A weak positive correlation (0.08) suggests minimal impact on emissions compared to other renewables.

• Nuclear Energy: A strong positive correlation (0.95) suggests its rise coincided with fossil fuel use, complicating its relationship with emissions.

These correlations suggest relationships but cannot confirm causation. Factors like policy changes and energy efficiency were not included, limiting the conclusions drawn.

Findings

Linear Regression Analysis

Coefficients	
fossil_fuel	0,23799583
solar	-0,24133032
wind	-0,16252614
Hydropower	-0,00210605
biofuel	-0,6881053
other_renewable	0,30028878
nuclear	-0,07612325

A linear regression was conducted to analyze CO_2 emissions using alternative energy sources (e.g., solar, wind, biofuels) and total fossil-based energy consumption (all_fossil) as features.

• **CO_2-Increasing Contributions**: Fossil-based energy consumption (0.24) and other renewables (0.30) are associated with higher CO_2 emissions.

• **CO_2-Reducing Contributions:** Solar (-0.24), wind (-0.16), biofuels (-0.69), and nuclear (-0.08) are linked to emissions reductions, while hydropower (-0.002) has minimal impact.

The model achieved an R^2 score of 0.89, explaining 89% of the variation in CO_2 emissions. However, it assumes linearity and excludes factors like policy changes and economic influences, limiting its scope.

Limitations

1. Causal Relationships:

The methods used, such as correlation and regression, identify associations but cannot establish causation. Factors like economic growth, energy efficiency, and policy changes were not included.

2. Exclusion of Other Emissions Sources:

The analysis focuses only on energy-related CO_2 emissions and does not account for emissions from land use changes, forestry, or other greenhouse gases like methane and nitrous oxide. These excluded factors are significant contributors to climate change and could provide a more comprehensive view of emissions trends.

3. Geographical Scope and Aggregation:

The focus on Europe and continent-level data overlooks variations among individual countries, such as differences in energy policies and emissions trends, limiting generalizability.

Conclusions

1. Continental Emissions and Population: Asia leads global CO_2 emissions due to its population and industrial growth, followed by North America and Europe. North America has the highest per capita emissions, while Europe shows a steady decline since 1990, reflecting progress in emissions reductions. Africa, South America, and Oceania have the lowest contributions.

2. Fossil-Based Energy and CO_2 Trends: In Europe, CO_2 emissions closely follow fossil-based energy trends, increasing until the late 1970s, stabilizing in the 1980s, and declining steadily after 1990. This decline aligns with the rise of non-fossil-based energy sources.

3. Non-Fossil-Based Energy Trends: Nuclear energy increased until the early 2000s but has since declined. Renewables like wind and solar began growing significantly in the late 1990s and early 2000s, while hydropower has remained stable, with minimal change in its contribution over time.

4. Correlation and Regression Analysis: Fossil fuels are strongly associated with increased CO_2 emissions, while renewables like wind, solar, and biofuels are linked to reductions. Regression analysis confirms the significant role of these renewables in lowering emissions, while nuclear energy shows mixed results and hydropower minimal impact.

Acknowledgements

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- No one gave me feedback

References

- Hannah Ritchie and Max Roser. “Energy.” Our World in Data. Accessed at: https://ourworldindata.org/energy