

1 Introduction

Energy has always been a critical topic, and its importance continues to grow. From energy poverty to the global energy mix and the climate crisis driven by fossil fuels, this issue remains at the forefront of discussions in the 21st century. I conducted a comprehensive data analysis on a dataset covering energy usage across 176 countries from 2000 to 2020. Through extensive visualizations and in-depth exploration, I examined global energy consumption trends and composition. Additional details on data preprocessing, time series visualizations, etc. can be found on the Github Repo.

2 Visual Analysis and Insights

2.1 How do the sources of electricity and their contributing percentages to overall electricity demand differ among countries when categorized by GDP per capita, and what is the general state of electricity access within these GDP buckets?

To provide a more detailed analysis, I divided this question into six key areas:

- I. Access to Electricity by Income Bracket
- II. Total Energy Consumption Across Income Brackets
- III. Per Capita Energy Consumption by Income Bracket
- IV. Renewable Energy's Share in Total Consumption
- V. Income-Based Distribution of Global Electricity Consumption by Energy Source
- VI. Distribution of Electricity Sources Within Each Income Bracket

I began by determining the income bracket for each country in each year. Using GDP per capita and the World Bank's annual income classifications, I categorized each country-year observation into one of four groups: High Income, Upper-Middle Income, Lower-Middle Income, or Low Income.

Next, to ensure comprehensive data coverage, I integrated the dataset with population data from the World Bank Group. I then calculated total energy consumption by multiplying population figures by per capita energy usage.

To explore the key areas mentioned, I generated several visualizations. These charts illustrate key patterns and differences across income groups.

2.1.i Visualizations and Initial Insights

Figure 1 illustrates the significant variation in electricity access across different income brackets. Although disparities exist across all income groups, low income countries experience the most pronounced gap, with just over 30% of the population gaining access to electricity during this period.

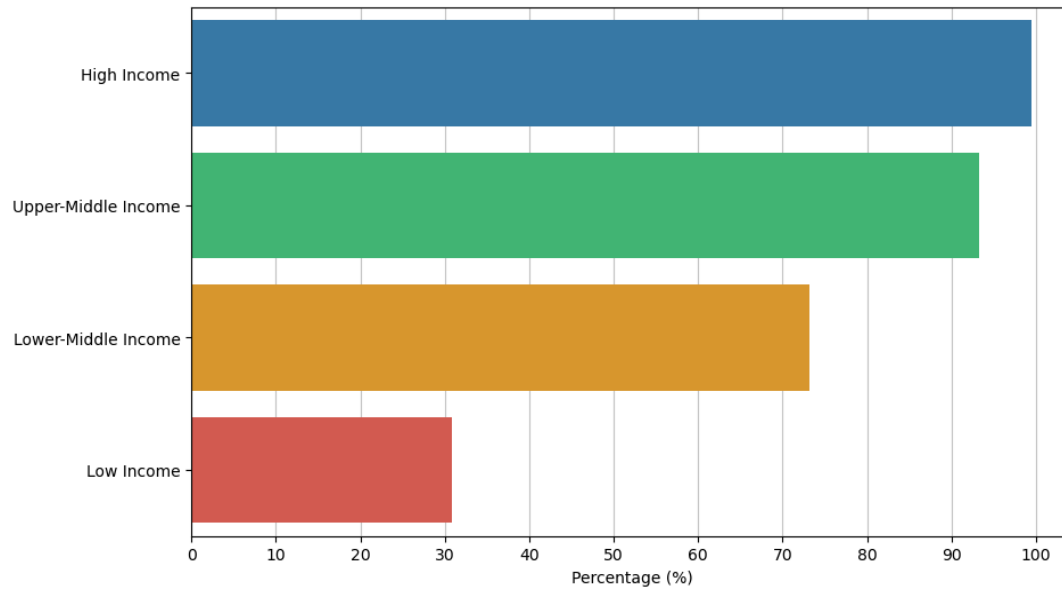


Figure 1: Access to Electricity by Income Bracket (2000–2020)

Figure 2 delves into actual energy consumption, highlighting a stark disparity between income groups. Each income bracket is significantly outpaced by the one just above it, with high income countries far exceeding upper-middle income countries, which in turn surpass lower-middle income countries, and so on. This gap is much more pronounced than the one observed in the electricity access graph, likely due to limited energy availability and cost-saving efforts in lower income regions.

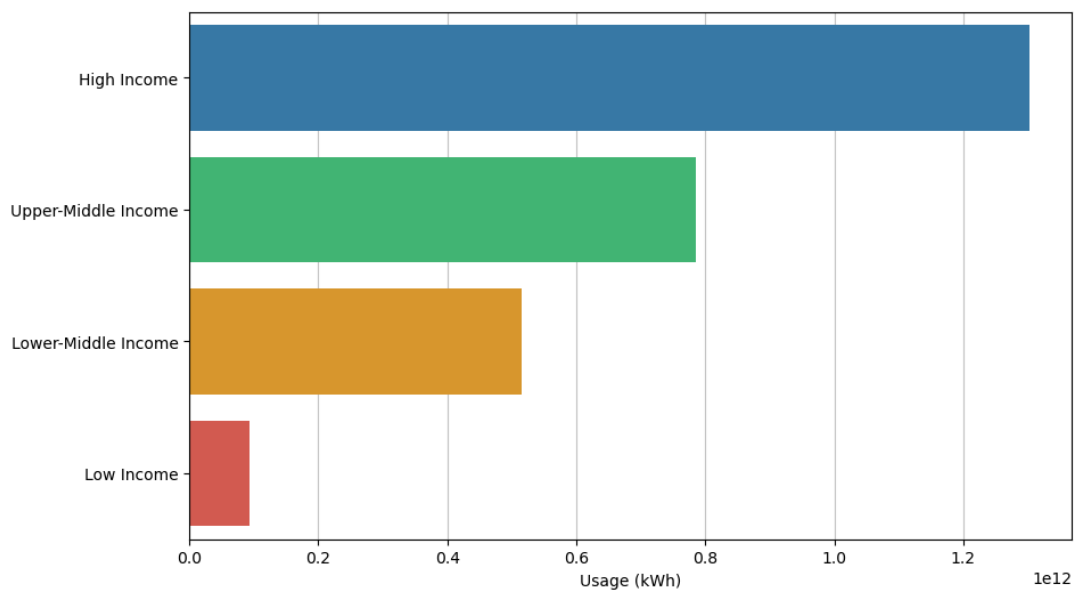


Figure 2: Total Electricity Usage by Income Bracket (2000–2020)

Figure 3 provides a more granular look at energy consumption per capita. As shown, individuals in high income countries consume more than three times the amount of energy as those in upper-middle income countries. This stark contrast underscores differing attitudes toward energy conservation and disparities in energy access across regions.

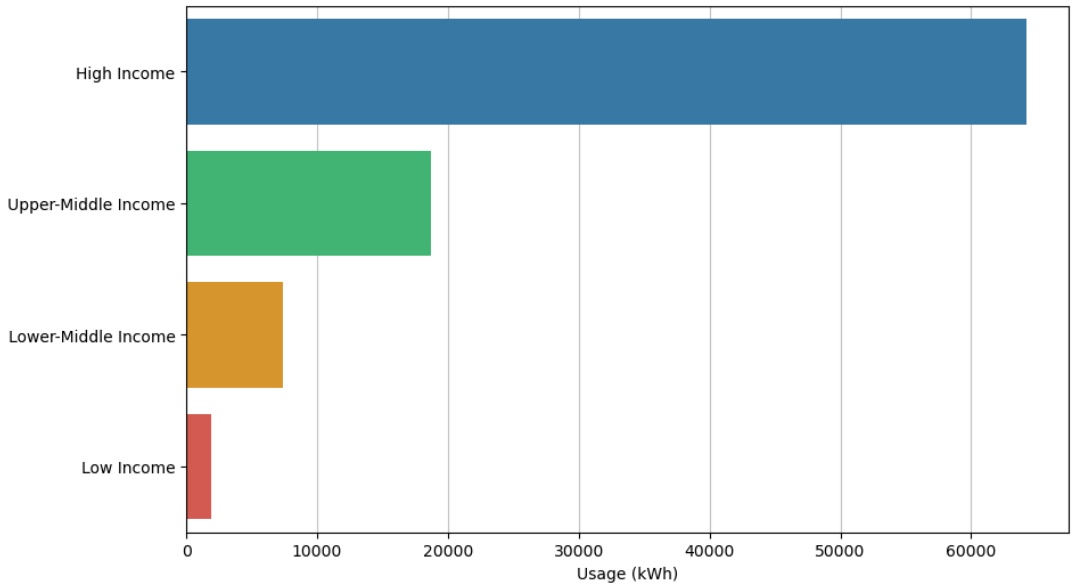


Figure 3: Energy Consumption Per Capita (2000–2020)

Figure 4 reveals a different trend, showing an inverse relationship between income level and the share of renewable energy in total consumption. This may be attributed to low income countries' limited access to traditional energy resources, prompting a greater reliance on renewable energy sources to address energy poverty.

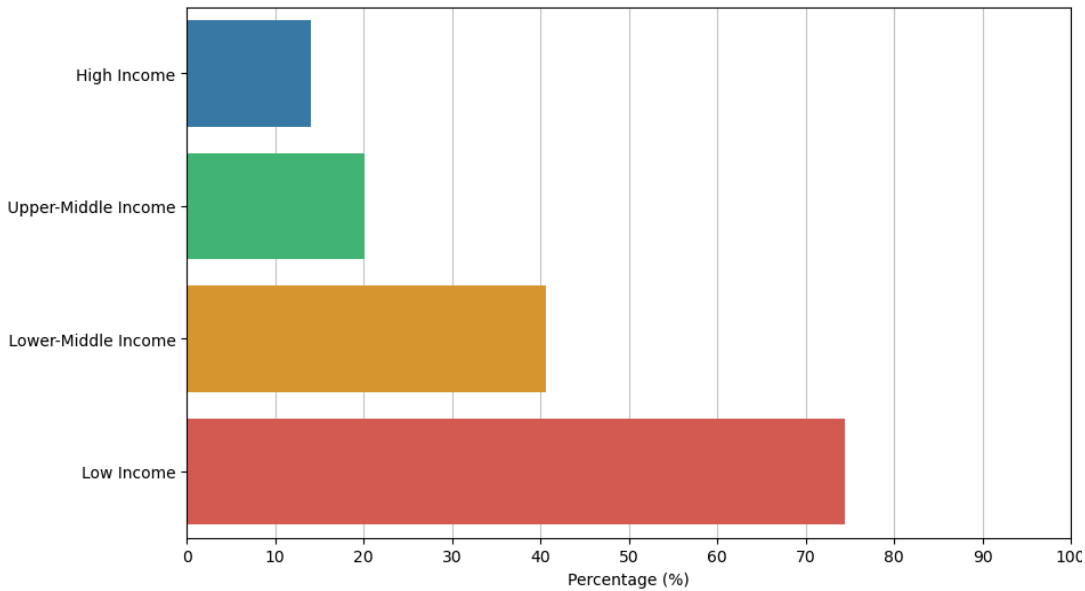
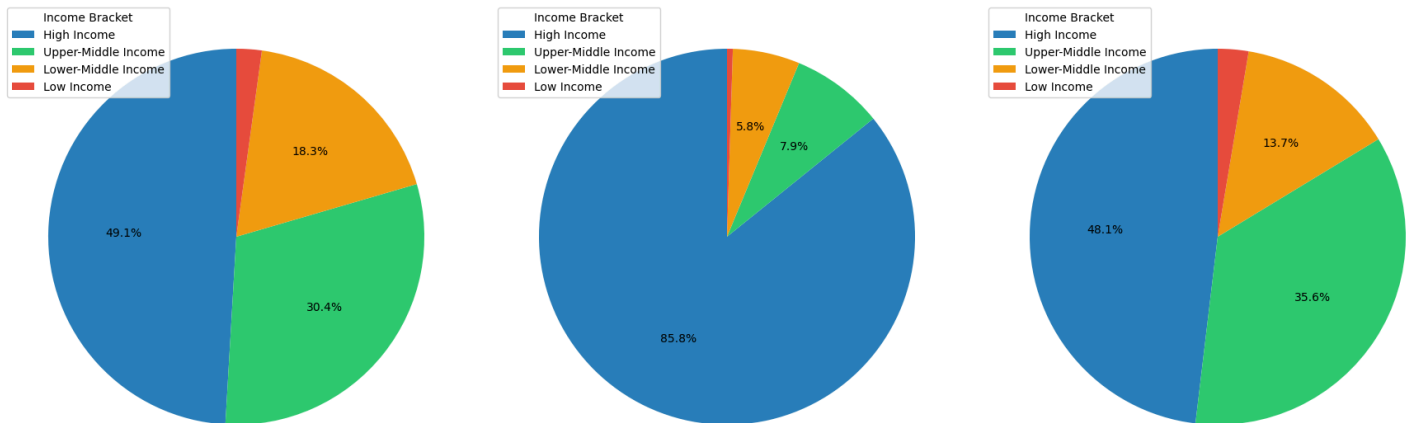


Figure 4: Renewable Energy Share in Total Consumption by Income Level (2000 – 2020)

Figures 5a, 5b, and 5c examine the percentage of global electricity supply consumed by each income bracket. The distribution of fossil fuels and renewables is similar, with high income countries accounting for about half of the total supply. However, the disparity is much more pronounced with nuclear energy. High income countries consume 85.8% of the supply, while all other income brackets each use less than 10%.



Figures 5a, 5b, and 5c: Income-Based Distribution of Global Electricity Consumption by Energy Source (2000 – 2020)

(5a = Fossil Fuels, 5b = Nuclear, 5c = Renewables)

Figure 6 examines the electricity source distribution within each income bracket. All brackets primarily rely on fossil fuels, with lower-middle income countries using them the most. Low and upper-middle income countries have a similar energy mix, showing no significant anomalies. The most striking difference is in high income countries, which depend on fossil fuels the least but use significantly more nuclear energy than any other income bracket.

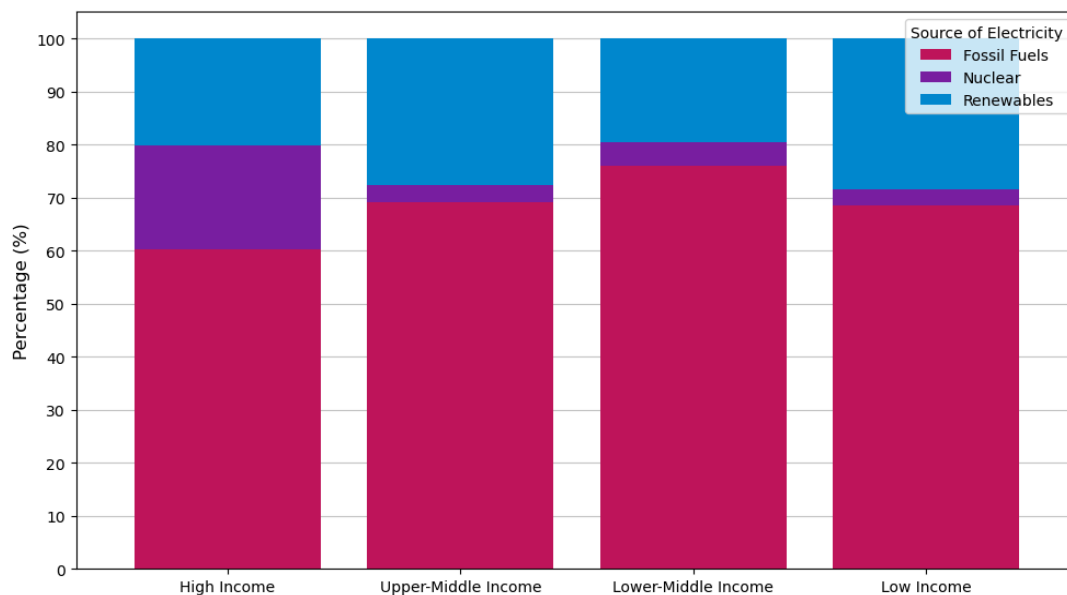


Figure 6: Distribution of Electricity Sources Within Each Income Bracket (2000–2020)

2.1.ii Key Takeaways

- Total energy and electricity consumption is closely tied to income, with high income countries using the most and consumption decreasing across lower income brackets.
- While energy access influences energy usage, the disparity in consumption is much larger than the disparity in access.
- There is an inverse relationship between income level and reliance on renewable energy—low income countries source over 70% of their energy from renewables, while high income countries rely on them for less than 15% of their energy consumption.
- Nuclear energy is predominantly used by high income countries, which account for 85.8% of global nuclear electricity consumption. In contrast, lower income brackets use very little, making nuclear a much more significant part of the energy mix in wealthier nations.
- Fossil fuels remain the dominant electricity source worldwide.

2.1.iii Additional Research

- BloombergNEF highlights this push for renewable energy in developing countries amid rising fossil fuel prices and fears about climate change ([Developing Countries Raise Their Clean Power Policy Ambitions | BloombergNEF](#))
- This Rockefeller Foundation article states that renewable energy initiatives will combat energy poverty and generate 500 million new jobs in Africa and Asia by 2030 ([New Research: Ending Energy Poverty by 2030 Can Create Nearly 500 Million New Jobs in Africa and Asia](#))
- World Nuclear Association claims that the long-term incentives for nuclear energy are hardly realized in deregulated markets due to the high-capital investment requirement and greater uncertainty ([Economics of Nuclear Power – World Nuclear Association](#))

2.2 When observing regional trends, how have preferences or dependencies on types of electricity supply evolved over time?

The primary dataset was missing information on regions, so I retrieved a dataset linking countries to their continents and sub-regions. Once I merged the two datasets together, the data was ready for exploration.

2.2.i Visualizations and Initial Insights

Figures 7a, 7b, and 7c illustrate global trends in fossil fuel, renewable, and nuclear energy usage in electricity supply across subregions from 2000 to 2020.

Fossil fuel and renewable energy usage have generally increased steadily across most subregions. However, Eastern Asia stands out with a rapid surge in both fossil fuel and renewable energy consumption. Another exception is North America, where fossil fuel usage has seen a slight decline over this period.

Nuclear energy trends, however, tell a different story. From 2000 to 2020, nuclear energy usage has remained stagnant or declined in most subregions, except for North America. The most notable decline occurred in Eastern Asia in the early 2010s, where nuclear energy consumption dropped significantly. However, by the late 2010s, the region had recovered and even surpassed its previous nuclear energy usage levels.

When looking at overall electricity usage, most regions maintain a consistent ranking across different energy sources—for example, Eastern Asia and North America are leaders across all electricity sources, maintaining high rankings in total energy consumption across fossil fuels, renewables, and nuclear energy. This is related to population, wealth, energy usage per capita, and other factors. However, two clear exceptions stand out: Latin America and the Caribbean rank significantly higher in renewable energy consumption compared to their usage of other energy sources, and Western Europe ranks much higher in nuclear energy usage than in other energy categories.

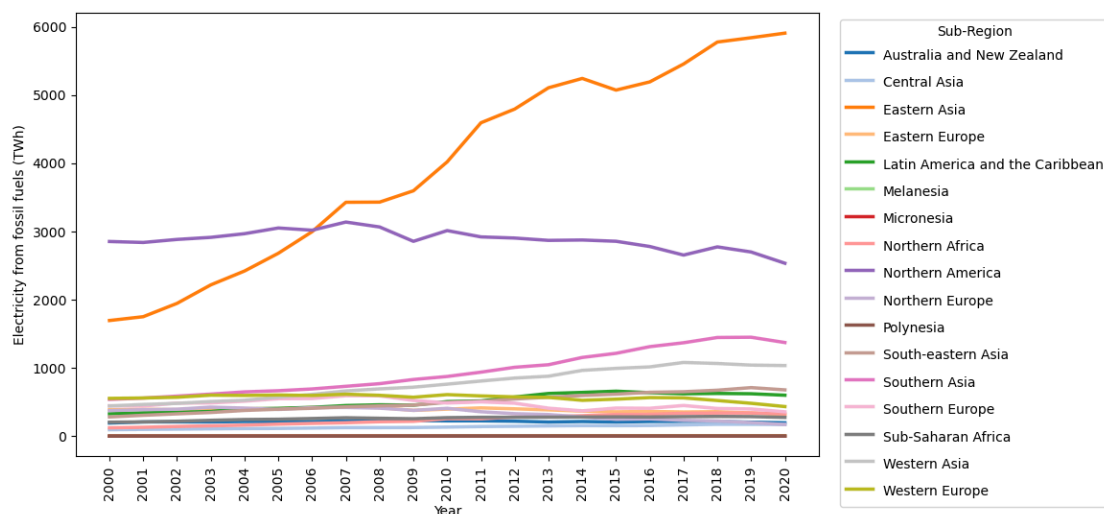


Figure 7a: Electricity Consumption from Fossil Fuel Energy by Subregion (2000 – 2020)

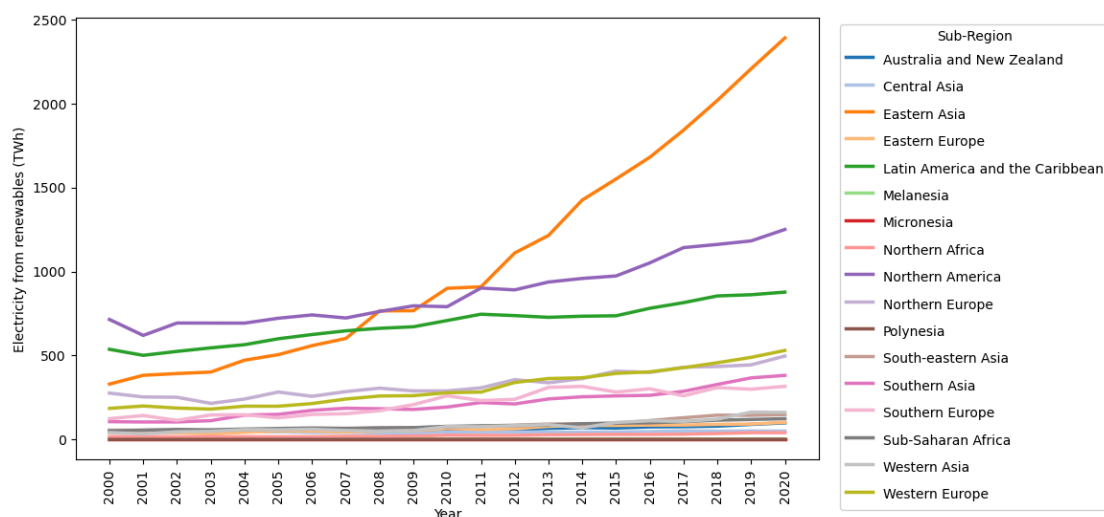


Figure 7b: Electricity Consumption from Renewable Energy by Subregion (2000 – 2020)

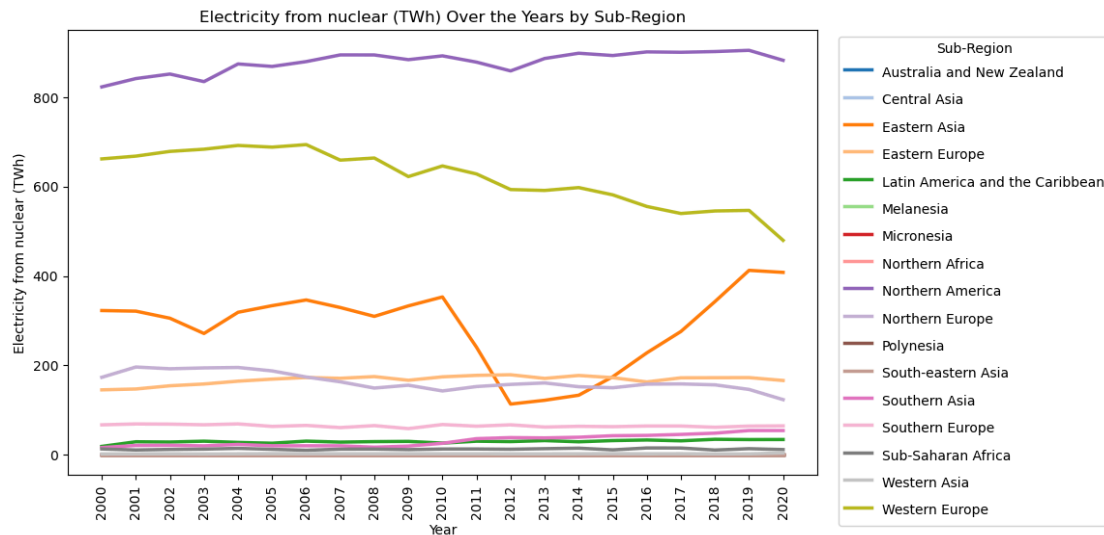


Figure 7c: Electricity Consumption from Nuclear Energy by Subregion (2000 – 2020)

2.2.ii Key Takeaways

- Global consumption of fossil fuels and renewable energy for electricity has generally increased gradually, while nuclear energy usage has remained stagnant.
- Latin America and the Caribbean have a strong reliance on renewable energy for electricity, while Western Europe depends heavily on nuclear energy, despite a decline in nuclear energy usage from 2000 to 2020.
- East Asia also relies significantly on nuclear energy but experienced a sharp decline in the early 2010s, with a recovery occurring towards the end of the decade.

2.2.iii Additional Research

- East Asia's sharp decline in nuclear energy in 2011 was due to the Fukushima nuclear disaster, where a 9.0-magnitude earthquake triggered a tsunami that flooded the reactors at Japan's Fukushima Daiichi plant ([Japan to increase reliance on nuclear energy in major shift after Fukushima](#))
 - “Japan now operates 14 commercial nuclear reactors, compared to 54 before the Fukushima disaster when 30% of the country's energy was from nuclear sources”
 - “Japan says it will increase its reliance on nuclear energy in a major policy shift as it seeks to meet growing demand from power-hungry sectors like AI and semiconductors.”
 - Japan is looking to increase its reliance on nuclear energy. “The country, which imports 90% of its fuel, needs to look to nuclear sources as part of its plan to cut back on carbon and be self-reliant on energy.”
- Nuclear power is cleaner and safer than fossil fuels, and it is less dependent on outside factors than renewables, but has a bad reputation due to fear of “nuclear meltdowns” and “weapon proliferation” ([Nuclear power is clean and safe. Why aren't we using more of it? – CNET](#))

- EU is a global leader on nuclear safety, developing the Euratom safety framework while aggressively pursuing nuclear solutions to energy, medicine, etc ([In focus: EU nuclear energy policy – why it matters to us all – European Commission](#))
 - Nuclear energy is far less taboo in France (, where it has brought “jobs and prosperity” to regions like Civaux ([Why The French Like Nuclear Energy | Nuclear Reaction | FRONTLINE | PBS](#)))
 - Italy phased out nuclear energy completely, but supports France’s nuclear power initiatives – 56 of the 163 nuclear reactors in Europe as of August 2023 were located in France ([Nuclear energy in Europe: Who is for and against it and why? | Euronews](#))
- Many countries in Latin America and the Caribbean are committing to hydropower and biofuels while also leveraging the “solar and wind potential” of the region ([How Brazil and Chile are leading Latin America’s energy transition | World Economic Forum](#))

2.3 In developing nations, is there a significant relationship between financial inflows (with the intent of increasing renewable energy usage) and the adoption of renewable and clean energy sources, and how does this impact their energy landscape and developmental trajectory?

I filtered the dataframe to include only rows where countries received financial inflows in a given year. Before that, I calculated total electricity usage and the percentage share of renewable energy. Next, I merged this filtered dataframe with the original one, capturing rows for the following year to track growth. Finally, I grouped the data by year to analyze growth and yearly averages.

2.3.i Visualizations and Initial Insights

Figure 8 shows a significant increase in renewable electricity from 2000 to 2020. In 2000, countries receiving financial support used less than 20 TWh of renewable electricity on average, whereas by 2020, this had risen to over 40 TWh. The most substantial growth occurred in 2019 and 2020.

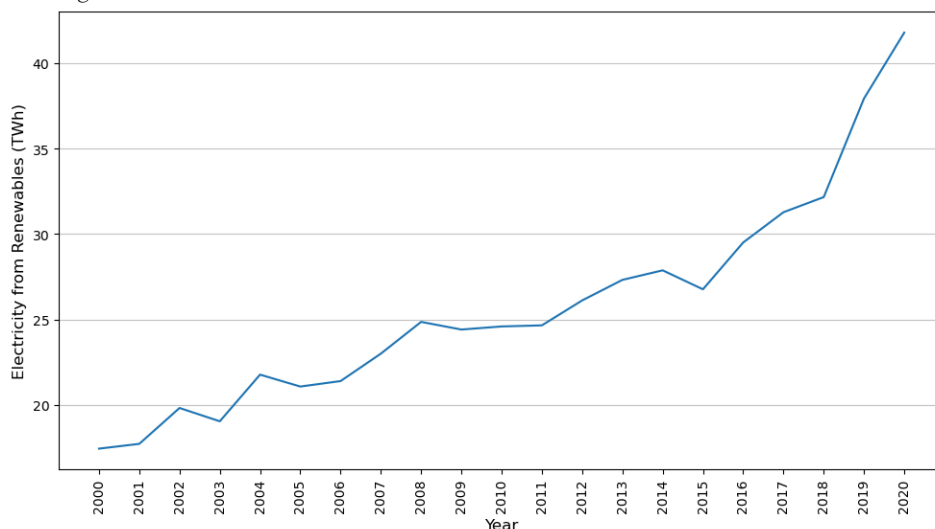


Figure 8: Average Annual Electricity Usage Sourced by Renewable Energy By Countries Receiving Financial Inflows

Figure 9 shows that despite the increase in renewable energy usage, its share of the total energy supply in countries receiving financial inflows has declined. This suggests that energy consumption from other sources has grown at a faster rate.

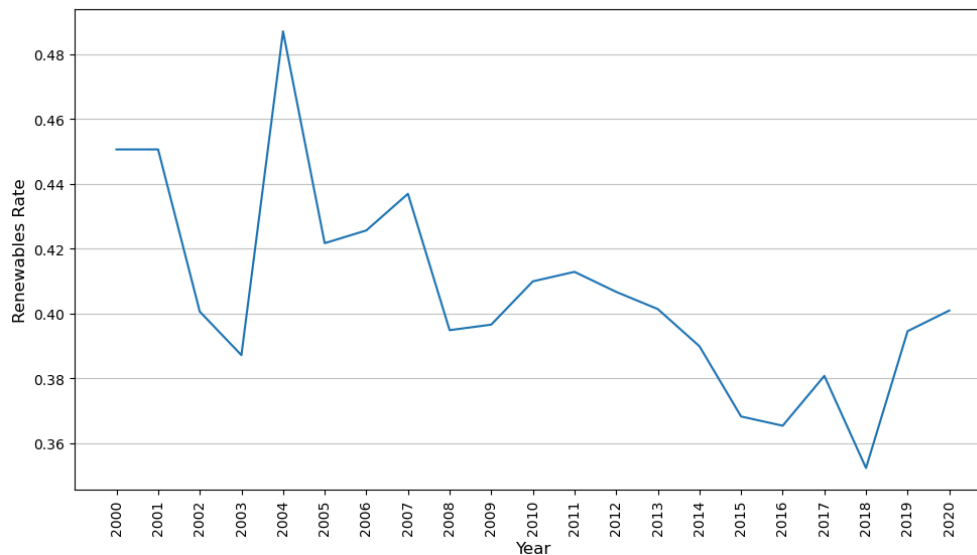


Figure 9: Percentage of Renewable Energy in Total Energy Output By Countries Receiving Financial Inflows

Figure 10 shows that after receiving financial inflows, countries consistently experience a net increase in renewable energy usage for electricity in the following year.

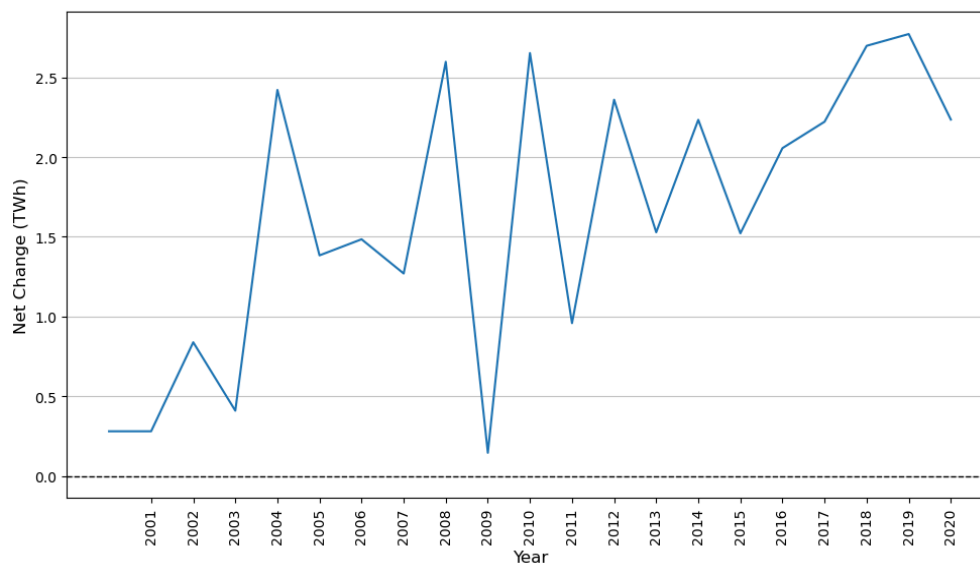


Figure 10: Net Increase in Renewable Energy Usage for Electricity By Countries Receiving Financial Inflows

2.3.ii Key Takeaways

- Financial inflows do not directly correlate with renewable energy initiatives, as other energy sources are growing at a faster rate.

- However, countries receiving financial inflows consistently experience an increase in overall renewable energy consumption, suggesting a possible correlation but not causation.

2.3.iii Additional Research

- There have been calls for increased financial investment in developing countries to boost renewable energy. However, the United Nations Conference on Trade and Development (UNCTAD) states that current funding remains far below the necessary levels ([UNCTAD calls for urgent support to developing countries to attract massive investment in clean energy | UN Trade and Development \(UNCTAD\)](#))

2.4 How do CO₂ emissions vary by income bracket? Which regions have contributed the most CO₂ emissions, and which have experienced the highest growth in emissions?

I grouped the data by income bracket to analyze the average and total CO₂ emissions.

2.4.i Visualizations and Initial Insights

Figure 11 shows that high income countries have historically been among the highest CO₂ emitters. However, they were recently surpassed by upper-middle income countries, which previously had emissions closer to lower-middle income nations. This shift is largely driven by China's rapid CO₂ emissions increase, coinciding with its GDP growth that elevated it to upper-middle income status in 2010. Low income countries produce by far the least, and they saw a noticeable drop in 2007, likely due to the reclassification of countries.

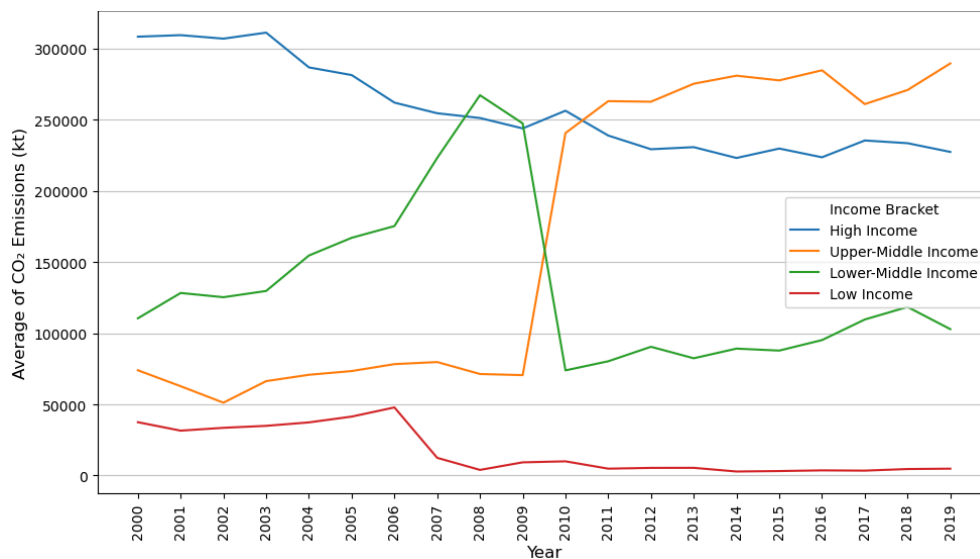


Figure 11: CO₂ Emissions Average By Income Bracket (2000–2020)

Figure 12 closely mirrors the trends in Figure 11, with upper-middle income countries—driven by China—contributing the most to total CO₂ emissions. A key difference is in high income countries, where total emissions have remained stable, but per capita emissions have declined. This is due to new high income countries with lower emissions joining the classification, demonstrating economic growth without proportional CO₂ increases.

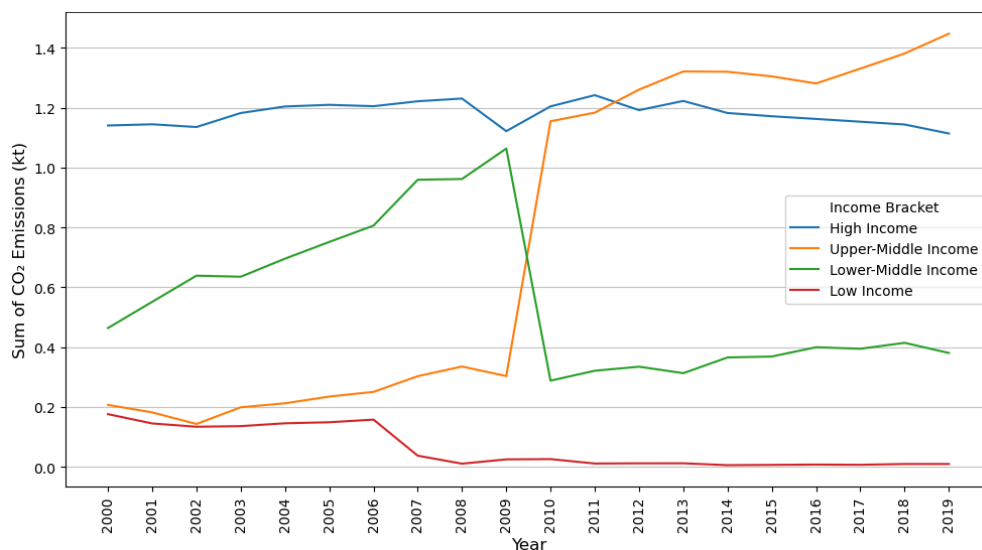


Figure 12: CO₂ Emissions Total By Income Bracket (2000–2020)

Figures 13a and 13b illustrate global CO₂ emission trends over time, highlighting significant contributors. The United States and Japan have consistently been high emitters, maintaining relatively stable annual emissions. In contrast, countries like China and India have experienced dramatic emission increases, coinciding with their economic growth and transition to higher income brackets.

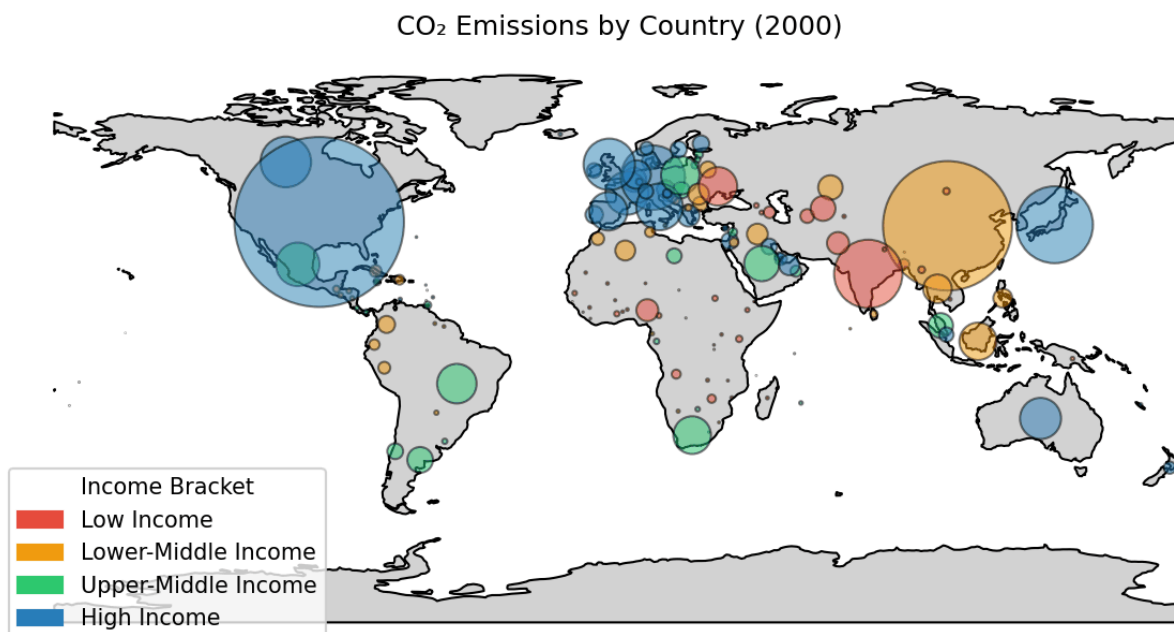


Figure 13a: Annual CO₂ Emissions Time Series (Fast) (2000–2020) (Visible on Github)

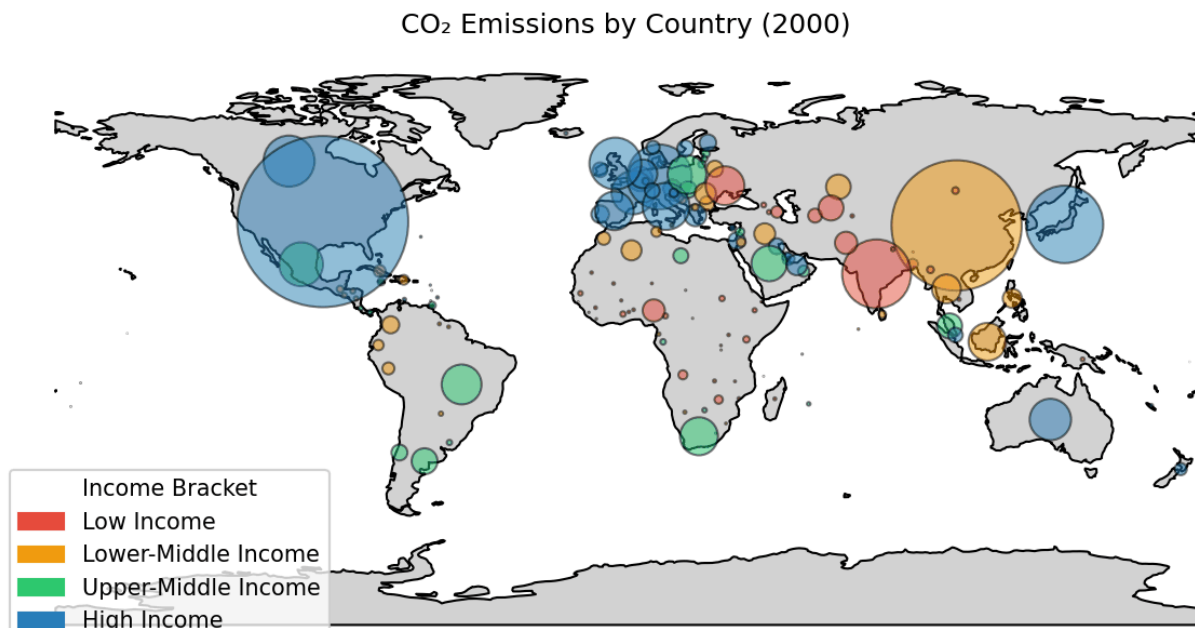


Figure 13a: Annual CO₂ Emissions Time Series (Slow) (2000–2020) (Visible on Github)

2.2.ii Key Takeaways

- High income countries were historically the largest CO₂ emitters but were recently surpassed by upper–middle income countries, largely due to China’s rapid emissions growth.
- China’s economic rise to upper–middle income status in 2010 coincided with a significant increase in its CO₂ emissions.
- Lower–middle income countries previously had similar emissions to upper–middle income countries, but the latter has since diverged due to rapid industrialization.
- Low income countries contribute the least CO₂ emissions and saw a noticeable drop in 2007, likely due to reclassification.
- Total emissions in high income countries have remained stable, but per capita emissions have declined, suggesting new entrants into the high income classification have lower emissions.
- Upper–middle income countries now dominate total emissions, reinforcing the link between industrial growth and CO₂ output.

2.2.iii Additional Research

- While the U.S. and many western countries have maintained their CO₂ emissions over the years, they are in large part responsible for the rapid increase of CO₂ emissions from China and India due to outsourced labor, creating products which eventually leave the country([View: Why we’re all to blame for China and India’s ‘filthy’ CO2 emissions | Euronews](#))

- While India has seen major growth in overall emissions, they have reduced its emission intensity (emission per unit of economic output) by 21% since 2005 and now has the fourth-largest renewable energy capacity globally ([View: Why we're all to blame for China and India's 'filthy' CO2 emissions | Euronews](#))
 - India is the only G20 nation with policies compatible with the Paris Accord target to mitigate climate change

3 Conclusion

The analysis of global energy consumption trends, the composition of electricity sources, and the relationships between income levels, renewable energy adoption, and CO₂ emissions paints a complex picture of the evolving energy landscape. Several key insights emerged from the exploration:

1. **Income and Energy Consumption:** The disparity between high income and low income countries is evident in both total energy consumption and electricity access. High income nations consistently dominate global energy usage, while low income countries continue to depend heavily on renewable energy due to limited access to fossil fuels. This underscores the challenge of energy poverty, especially in low income regions where limited access to traditional energy resources has led to a reliance on renewables as a means of addressing energy needs.
2. **Renewable Energy Adoption:** Financial inflows aimed at boosting renewable energy usage in developing countries have had a measurable impact, though their effectiveness has been tempered by the faster growth in consumption from other energy sources. Countries receiving financial support for renewable energy showed consistent increases in renewable electricity consumption, suggesting that financial aid can catalyze change. However, other factors, such as the growth of fossil fuel-based energy consumption and the higher cost of renewables, have slowed the transition.
3. **Regional Trends and Nuclear Energy:** The regional analysis revealed stark differences in how electricity is sourced. While Eastern Asia and North America remain major consumers of fossil fuels and nuclear energy, Latin America has been a leader in renewable energy adoption. The specific case of Eastern Asia, particularly China, illustrates the significant role industrialization and rapid economic growth play in shifting energy consumption patterns. As noted in the additional research, East Asia's decline in nuclear energy usage in the early 2010s was a direct result of the Fukushima nuclear disaster in 2011, but this was later reversed as China and other countries in the region sought to increase their nuclear capacity in response to rising energy demand and climate concerns. Furthermore, regions like Western Europe show a marked preference for nuclear energy, despite a general decline in its usage over the past two decades.
4. **CO₂ Emissions and Economic Growth:** High income countries, long the largest CO₂ emitters, have recently been surpassed by upper-middle income nations, particularly China, whose rapid industrialization and economic growth have driven a sharp increase in emissions. This trend is consistent with the findings that suggest a direct link between economic growth and CO₂ output. However, in high income countries, total

emissions have stabilized, and per capita emissions have declined, as many of these nations have moved toward cleaner energy solutions. This trend highlights the potential for decoupling economic growth from carbon emissions when cleaner technologies are adopted, a shift that has been aided by the international policies and frameworks discussed in the additional research.

5. **Role of International Financial Flows:** The additional research from sources like the United Nations Conference on Trade and Development (UNCTAD) and the Rockefeller Foundation underscored the importance of international investment in clean energy, especially in developing countries. While financial inflows are vital, they are still not sufficient to meet the scale of energy transition required. UNCTAD has called for greater investments in clean energy projects, while the Rockefeller Foundation emphasized the significant job creation potential of ending energy poverty through renewable energy initiatives. These insights point to the need for coordinated global efforts, including increased funding, to accelerate the energy transition in developing regions.
6. **Nuclear Energy's Role in the Energy Mix:** The additional research also highlighted the evolving role of nuclear energy in the global energy mix. In Europe, nuclear energy has faced significant challenges, including public perception issues and the high capital costs of building new plants. However, countries like France have remained strong proponents of nuclear energy, which has helped to provide a stable, low-carbon source of electricity. This contrasts with other regions like Italy, which phased out nuclear energy completely but still supports nuclear initiatives in neighboring countries like France. These examples emphasize that while nuclear energy is viewed with caution in many parts of the world, it remains an important part of the energy mix, especially in countries that have made long-term investments in its infrastructure.

4 Final Thoughts

The global energy landscape is characterized by stark disparities across income levels, regions, and energy sources. The findings from this research highlight the complexity of transitioning to renewable energy, particularly in developing nations, and the role of financial support in driving this change. While the shift towards renewables is occurring, the growth of fossil fuel consumption and the challenges posed by nuclear energy adoption must also be addressed. Future research should continue to explore these dynamics, with a focus on how financial inflows, international policy, and technological innovation can accelerate the transition to a more sustainable and equitable global energy system. By continuing to invest in clean energy, fostering international cooperation, and promoting energy equity, we can work toward achieving both global energy security and a sustainable future for all.