Project Assignment - CO2 Emissions

By Sanne Kuijpers

Introduction

Carbon dioxide (CO_2) emissions are a growing issue, they change the world as we know it by disrupting ecosystems, causing climate change and polluting our air. Understanding the consequences is important, but grasping how carbon dioxide (CO_2) emissions are caused and therefore can be limited is critical to addressing this issue. However, these emissions vary widely across countries and are always influenced by economic, technological, and political factors. This analysis seeks answers to some of these causes by analysing three key questions:

1. What is the biggest predictor of a large CO_2 output per capita of a country? By looking at socio-economic and energy-related variables, this analysis identifies some factors associated with high CO_2 emissions per capita.
2. Which countries are making the biggest strides in decreasing CO_2 output? As nations implement policies and technologies to reduce CO_2, it is important to learn from these countries and see how we can adapt this worldwide.
3. Which non-fossil fuel energy technology will have the best price in the future? The transition to renewable energy is critical for stopping climate change. By answering this question we determine which energy technology is likely to become the most cost-effective in the future.

To analyse these questions, data from "Our World in Data" and “NREL” is used. For the analyses Python is used to clean, process, and interpret the data, applying statistical and visual techniques to answer the research questions. This report provides an analysis of the methodologies employed, the results obtained, and their implications for global climate change. By understanding the factors driving emissions, finding successful strategies, and watching future trends, this paper adds to a better understanding of the future.

Methods

Tools and Techniques for Data Cleaning and Analysis

The analysis was performed using Python with several libraries. I used pandas for data loading, cleaning, and manipulation, as it was the most straightforward for my tasks. For visualizing the data, I employed matplotlib and seaborn to create plots and graphs to better understand the patterns in the data. For statistical analysis, including linear regression, I relied on scikit-learn. Numpy was also used for numerical computations, such as applying transformations and calculating regression slopes.

For each dataset, I began by cleaning the data: removing missing values, eliminating unnecessary columns, and renaming columns to make the data more intuitive. In cases where there were multiple datasets, I merged them to facilitate direct comparisons between variables. Additionally, I generated graphs to provide visual context for the data's patterns.

Biggest Predictor of Large CO2 Output Per Capita

To explore the variables that most strongly predict large CO2 emissions per capita, I worked with four datasets: protein consumption, domestic aviation emissions, energy consumption, and per capita CO2 emissions. I started by filtering relevant columns and cleaning up the data. For protein consumption, missing values were replaced with zeros using `fillna(0.0)`. I then aggregated the data to sum protein consumption by country, and dropped unnecessary columns. Similarly, the data for CO2 emissions per capita was simplified to include only relevant columns. The domestic aviation and energy use data were also filtered for relevant columns and renamed for clarity.

For analysis, I calculated the Pearson correlation coefficient using the `corr()` method to assess the relationships between each variable and CO2 emissions per capita. I also created scatter plots to visualize these relationships.

Countries Decreasing CO2 Output

To identify which countries are making the most progress in reducing CO2 emissions, I analysed datasets on annual CO2 emissions, renewable energy share, and climate policy support. I filtered the CO2 emissions data to focus on years from 2010 onwards, then calculated the slope of emissions for each country using numpy’s polyfit function. Countries with a negative slope were selected as those showing a decrease in emissions. The top 20 countries with the steepest decreases were further analyzed.

To examine the impact of climate policies, I filtered policy support data to include only the top countries. I compared the policy support levels of these countries with the global average, visualizing the results using bar charts, with a reference line for global policy support.

Future Price of Non-Fossil Fuel Energy Technologies

For analysing the cost trends of non-fossil fuel energy technologies, I filtered the data to focus on the "Moderate" scenario, the "R&D" case, and LCOE as the core metric. I grouped the data by year and technology and computed the mean cost for each group. A pivot table was created to structure the data with years as rows and technologies as columns. Then, I applied linear regression to calculate the slope of each technology’s cost over time, which helped determine the rate of cost reduction. Finally, I visualized these trends using line plots to compare how the cost of each technology evolves over the years.

Results

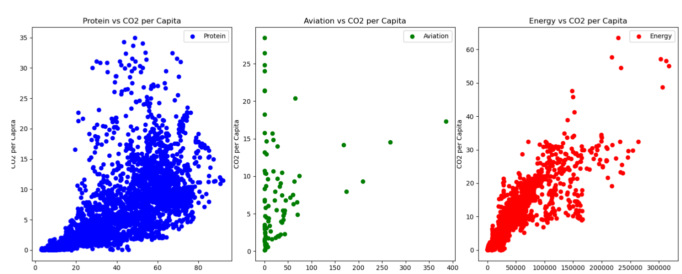
Biggest Predictor of a Large CO2 Output per Capita

The analysis reveals that energy use is the most significant predictor of high CO_2 emissions per capita, with a strong correlation coefficient of 0.89. This indicates a nearly direct relationship between increased energy consumption and higher CO_2 emissions per individual. The magnitude of this correlation suggests that energy policies and consumption patterns play a pivotal role in shaping a country's carbon footprint.

Protein consumption also demonstrates a notable correlation of 0.70, which, while weaker than energy use, is still substantial. This relationship may reflect the environmental impact of resource-intensive food production, such as livestock farming, which contributes heavily to greenhouse gas emissions.

Aviation, with a correlation of 0.18, shows a smaller but still relevant impact on CO_2 emissions per capita. While aviation contributes less directly to overall emissions compared to energy use or protein consumption, it remains a visible factor, particularly in countries with high per capita air travel.

Dataset	Correlation Coefficient
Protein consumption	0.7038047908827726
Aviation	0.18106977743021632
Energy use	0.8947424841734891



In this graph the correlation coefficient is visualised. The results underscore the dominant role of energy use in driving CO_2 emissions, as visualized in the accompanying graph. These findings highlight the critical need for targeted measures to improve energy efficiency, transition to renewable sources, and encourage sustainable consumption practices to mitigate carbon footprints globally.

Countries making the biggest strides in decreasing CO2 output

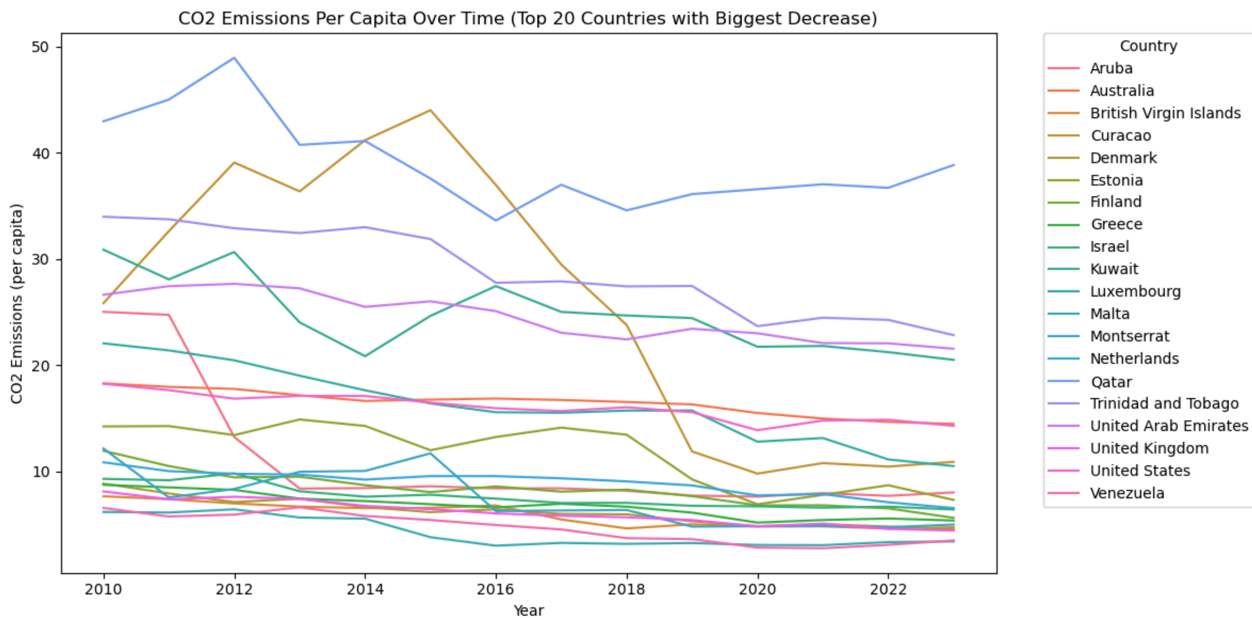
The analysis shows the top 20 countries with the most significant reductions in per capita CO_2 emissions between 2010 and the most recent available year. These countries show negative slopes in CO_2 emissions per capita, indicating a consistent decrease over time. The slope values, calculated using linear regression, reflect the annual rate of change in emissions per capita.

The country with the steepest reduction was Curaçao, with a slope of -2.40, showing a substantial annual decrease in emissions. Following Curaçao were Aruba (-1.02) and Trinidad and Tobago (-0.98), both showing significant progress. These reductions suggest active efforts to curb emissions, possibly through energy transition strategies or shifts in economic activities. Interesting to note is that the difference between Curaçao and the following countries is significant.

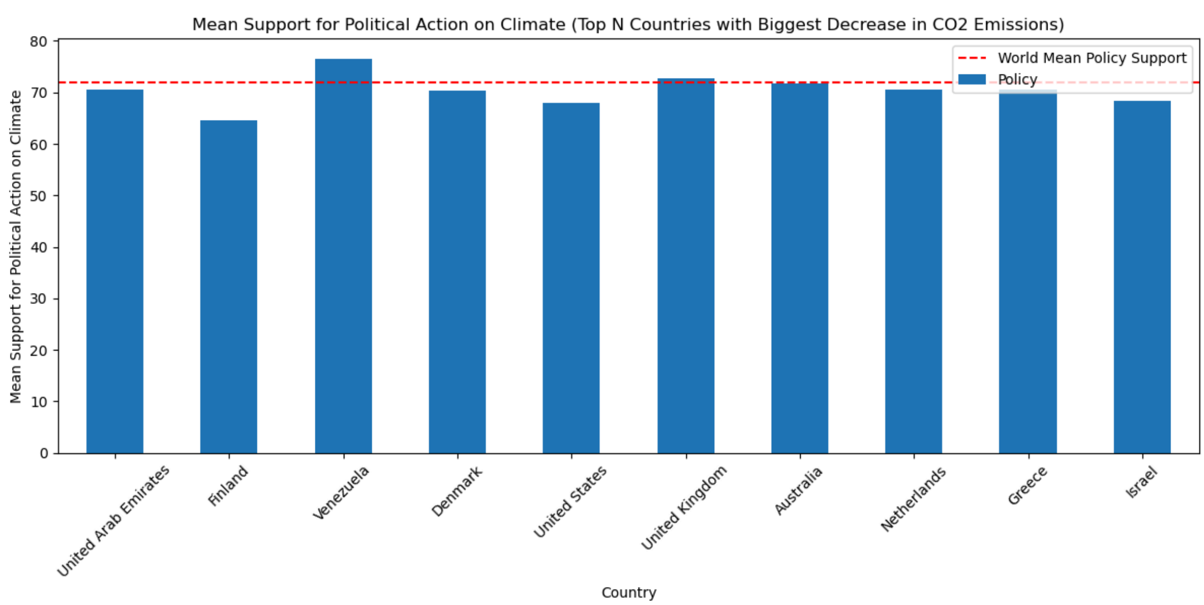
European countries like Luxembourg (-0.84), Estonia (-0.61), and Denmark (-0.30) also rank highly, highlighting the region's strong policies on renewable energy adoption and emission reduction targets. Similarly, Middle Eastern nations, including Qatar (-0.69), Kuwait (-0.64), and the United Arab Emirates (-0.50), exhibited noteworthy declines, reflecting regional diversification away from oil dependency.

Other countries such as the United States (-0.29), United Kingdom (-0.28), Australia (-0.27), and Netherlands (-0.27) achieved moderate reductions, driven by investments in cleaner technologies and policy shifts toward sustainable energy. Smaller territories, such as Montserrat (-0.51) and the British Virgin Islands (-0.25), also made the list, demonstrating that even smaller nations or regions can make measurable contributions to CO_2 reduction.

Top 20 Countries	**Slope**
Curacao	-2.40
Aruba	-1.02
Trinidad and Tobago	-0.98
Luxembourg	-0.84
Qatar	-0.69
Kuwait	-0.64
Estonia	-0.61
Montserrat	-0.51
UAE	-0.50
Finland	-0.38
Venezuela	-0.31
Denmark	-0.30
US	-0.29
UK	-0.28
Malta	-0.28
Australia	-0.27
Netherlands	-0.27
Greece	-0.27
British Virgin Islands	-0.25
Israel	-0.24



As additional analysis I looked at the support for political action in these top 20 countries. There was only data available on 10 countries from the top 20. Interesting to see is that 7 of these 10 countries have a government supporting the action on climate less than the world average.



This ranking underscores the global distribution of efforts to decrease per capita CO_2 emissions, with significant contributions from both developed and developing regions. The results point to a combination of technological advancements, policy support, and shifts in energy infrastructure as drivers of these reductions.

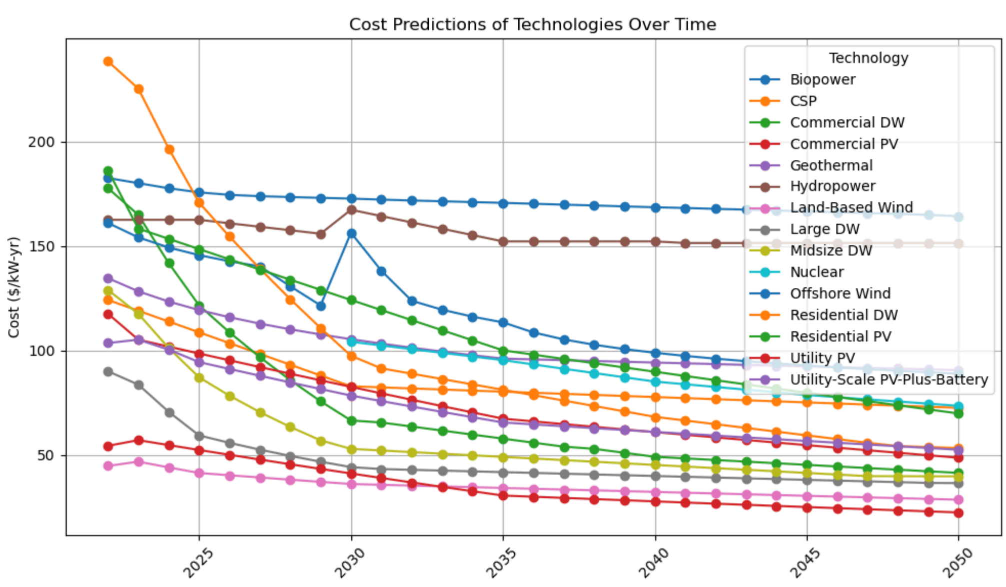
Best priced non-fossil fuel energy technology in the future

The analysis I did for the non-fossil fuel energy technologies shows that Residential Direct Water Heating (DW) is the most promising for future price reduction, with a slope of -5.32. It is showing the highest decrease in cost over time. Commercial DW follows closely with a slope of -3.68, and after that comes Residential PV (Photovoltaic) with -3.45. These strong declines suggest that these technologies are becoming more cost-effective, paving the way for wider adoption in the future.

When we look at the other technologies such as Offshore Wind (-2.63), it also shows potential to reduce cost, but not as much as the residential and commercial DW. Midsize DW (-2.25) and Utility-Scale PV-Plus-Battery (-1.81) also show positive options for the future if they manage to reduce costs even more.

In contrast, technologies like Hydropower (-0.5) and Biopower (-0.5) show minimal cost reduction. They are still a viable option for renewable energy use but maybe not in all sectors. Their slower cost declines suggest they may play a lesser role in future energy transitions compared to other more quickly advancing technologies.

Technology	**Slope**
Residential DW	-5.32
Commercial DW	-3.68
Midsize DW	-2.25
Large DW	-1.25
Offshore Wind	-2.63
Land-Based Wind	-0.55
Residential PV	-3.45
Commercial PV	-2.16
Utility PV	-1.24
Utility-Scale PV-Plus-Battery	-1.81
Biopower	-0.5
Hydropower	-0.5
Nuclear	-1.58
CSP	-1.48
Geothermal	-1.29



Discussion

This analysis shows how complex it is to address global CO_2 emissions and work towards using more sustainable energy solutions. By focusing on three key questions, I tried to get a clearer understanding of the current situation and future possibilities for renewable energy.

One of the most interesting findings is the strong relationship between energy use and CO_2 emissions per capita. The correlation coefficient of 0.89 shows that energy consumption is the main cause of high energy consumption. This shows the need for efficiency improvements and a shift toward renewable energy specifically focused on energy use. While protein consumption also showed a notable correlation, its connection to emissions is not as profound. This could imply that there are other factors contributing to this such as farming and the meat industry that is causing emission, not the consumption itself. This finding could inspire further exploration into sustainable agricultural practices as a strategy to create a green energy-focused future.

The analysis of countries reducing CO_2 emissions shows promising progress in some areas but also highlights notable differences. Curaçao's sharp decrease illustrates how quickly a country can change, while the smaller reductions seen in other nations, particularly industrialized ones, reveal ongoing challenges and show how difficult it is. It is also notable that many of these countries are below the global average when it comes to government support for climate policies. This shows a disconnect between political intentions and real-world implementation. If we want to achieve a more consistent growth it should strengthen each other and grow aligned. Strengthening policies in industrialised countries and undertaking action will do more on a bigger scale. The countries that are now making big strides are often small countries that might find it easier to change their way of sourcing energy than the bigger countries that rely heavily on fossil fuels.

The research on renewable energy cost trends provide multiple insights into the future of green energy. The cost reductions for technologies like Residential DW, Commercial DW, and Residential PV suggest a promising future for affordable and accessible energy solutions. However, slower advancements in technologies like Hydropower and Biopower might also be interesting to look at for they may have benefits or still be the best option in specific circumstances. The goal is to not rely on one type of energy source but to improve many of the green energy sources to give the world more options and make the best choice for every situation.

Conclusion

This project offers three main key takeaways.

1. Energy use is the most significant predictor of CO_2 emissions per capita, reaffirming the importance of targeting energy consumption in climate strategies.
2. Several countries are making notable progress in reducing emissions, but global efforts remain inconsistent. Enhanced international collaboration and policy support are critical for amplifying these successes.
3. Residential DW and PV technologies show the greatest promise for cost reduction, positioning them as pivotal in the renewable energy transition.

This analysis has many limitations and based on further research more specific conclusions could be drawn. In follow-up research it might be interesting to look at more factors such as urbanisation, industrialisation or regional changes when looking at the biggest predictor for CO2 emission. Also, the source used to predict the cost trends was a very difficult source and the outcomes are only based on that one. It would be good to look at other data to support the claim for Residential DW to be the most cost efficient.