Winc Academy Final Project Assignment: CO_2 emissions

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1. Introduction

Global greenhouse gas emissions have increased rapidly over the last 50 years and have led to rising global average temperature. Among these emissions, CO_2 has played the most critical role in amplifying the greenhouse effect. There are large differences in emissions across the world, with some countries making progress in reducing their CO_2 output. While current climate policies have led to reductions in emission, they remain insufficient to limit global temperature rise to below 2 degrees Celsius. To tackle this challenge, further reductions in CO_2 emissions have become a priority for policymakers and industries. A key strategy in this challenge involves accelerating the transition to non-fossil fuel energy sources.

This report focuses on analysing three research questions related to CO_2 emissions trends:

1) What is the biggest predictor of a large CO_2 output per capita of a country?
2) Which countries are making the biggest strides in decreasing CO_2 output?
3) Which non-fossil fuel energy technology will have the best price in the future?

The research questions and corresponding methods, analysis and conclusions will be discussed in this report in this order.

2. Analysis

2.1 Research Question 1: What is the biggest predictor of a large CO_2 output per capita of a country?

2.1.1 Methods

To identify factors that are most strongly associated with high CO2 emissions we calculated the correlation coefficients of different possible predictors (variables) in relation to CO2 emission per capita. We considered the variables Gross domestic product (GDP per capita in $), population and energy per capita (primary energy consumption per capita, measured in kilowatt-hours per person). To visualize the relationships of these variables with CO2 emissions we made scatterplots of the relationships with a correlation coefficient of >0.5. After plotting the scatterplots one outliers (CO2 > 350 metric tons) has been removed. For GDP per capita a log transformation was done and the correlation coefficient of the log data was determined. Based on the highest correlation coefficient the biggest predictor of a large CO2 output was identified.

2.1.2 Analysis

In Table 1 correlation coefficients of the predictor variables in relation to CO2 per capita are shown. Correlation coefficient for GDP per capita is 0.6, for energy per capita 0.7 and for population and primary energy consumption 0 and 0.2 respectively.

Table 1: Correlation matrix

Predictor variable	Correlation coefficient CO2 per capita
energy per capita	0.724
GDP per capita	0.604
population	0.004
primary energy consumption	0.163

Since the correlation coefficients for energy and GDP per capita are > 0.5 these variables are plotted against CO2 per capita in scatterplots. Figure 1 shows the scatterplot of the relation of energy per capita and CO2 per capita. There is a positive linear relationship between energy per capita and CO2 per capita. The higher the energy consumption per person in a country the higher the CO2 output per person of a country. One outlier value (CO2 emission > 350 metric tons) has been removed resulting in a correlation between energy per capita and CO2 per capita of 0.82.
Figure 2 shows the scatterplot of the relationship of GDP per capita and CO2 per capita. The correlation between CO2 per capita and GDP per capita is 0.67.

Scatterplot of the relationship of energy per capita and CO2 per capita

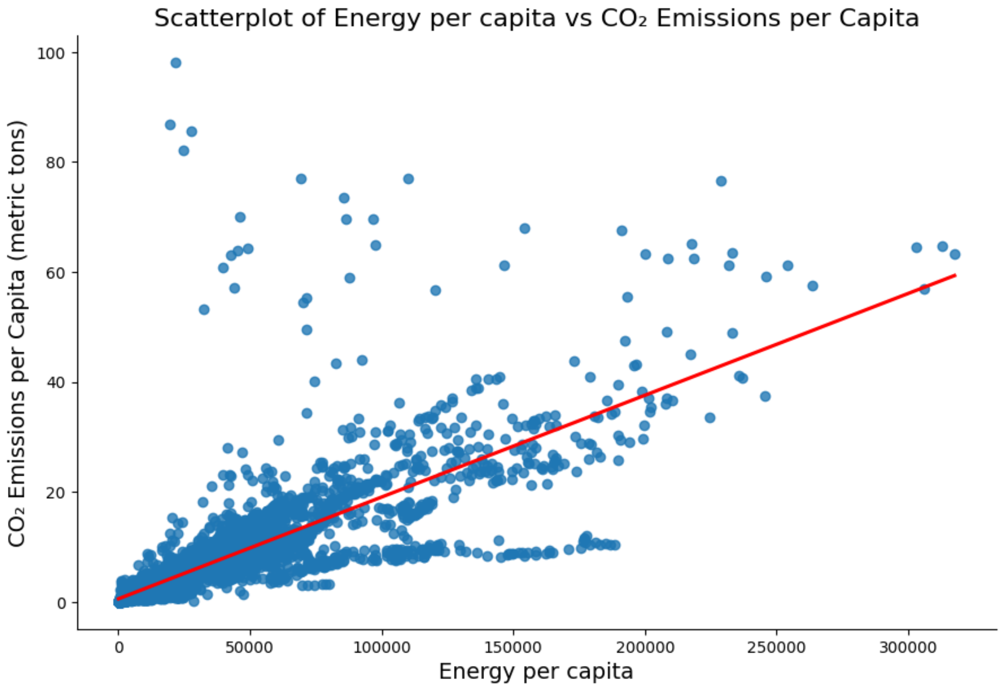


Figure 1. Scatterplot of the relation of energy per capita versus CO2 per capita. Correlation between CO2 per capita and energy per capita: 0.82.

Scatterplot of the relationship of GDP per capita and CO2 per capita

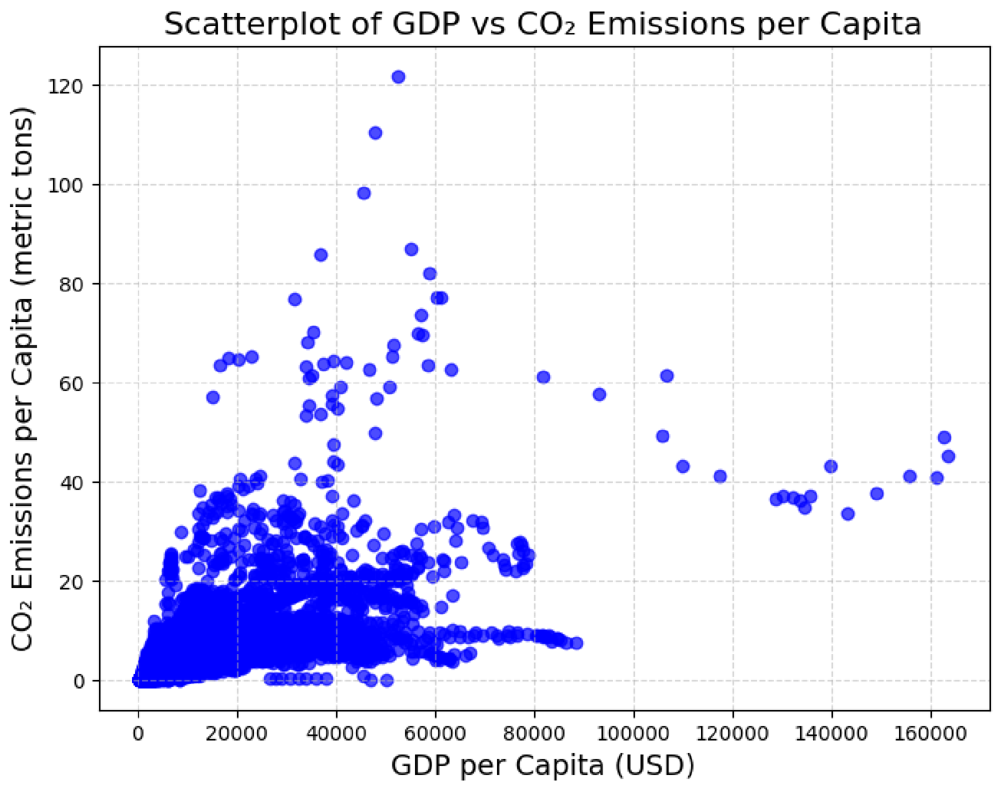


Figure 2. Scatterplot of the relationship of GDP per capita and CO2 per capita.
The correlation between CO2 per capita and GDP per capita is 0.67.
For the low-to-middle incomes CO2 emissions strongly correlate with how much money we have. The richer we are, the more CO2 we emit. But this relationship does

not hold true at higher incomes. Many countries have managed to achieve economic growth while reducing emissions. They have decoupled the two which is apparent from the scatterplot.

The relationship between GDP per capita and CO2 emissions per capita is non-linear. And GDP per capita and CO2 emissions have skewed distributions (data not shown). Therefore, in Figure 3 the scatterplot of the relationship between GDP per capita and CO2 per capita after log transformation of the data is shown. The correlation coefficient for log GDP per capita and log CO2 per capita is 0.86.

Scatterplot of log transformed GDP per capita and CO2 per capita

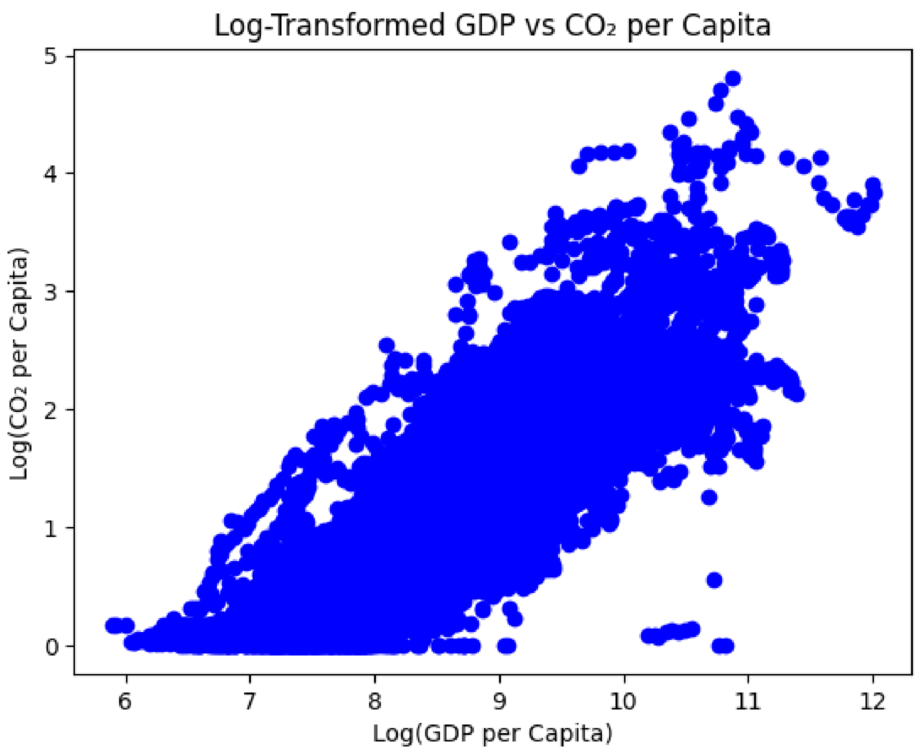


Figure 3: Scatterplot of log transformed GDP per capita and CO2 per capita. The correlation coefficient for log GDP per capita and log CO2 per capita is 0.86.

2.1.3 Conclusion

We can conclude that GDP per capita (log transformed) and energy per capita are the biggest predictors of a large CO2 output per capita, indicating that richer countries and countries with higher energy consumption per capita emit more CO2 per person.

2.2 Research Question 2: Which countries are making the biggest strides in decreasing CO_2 output?

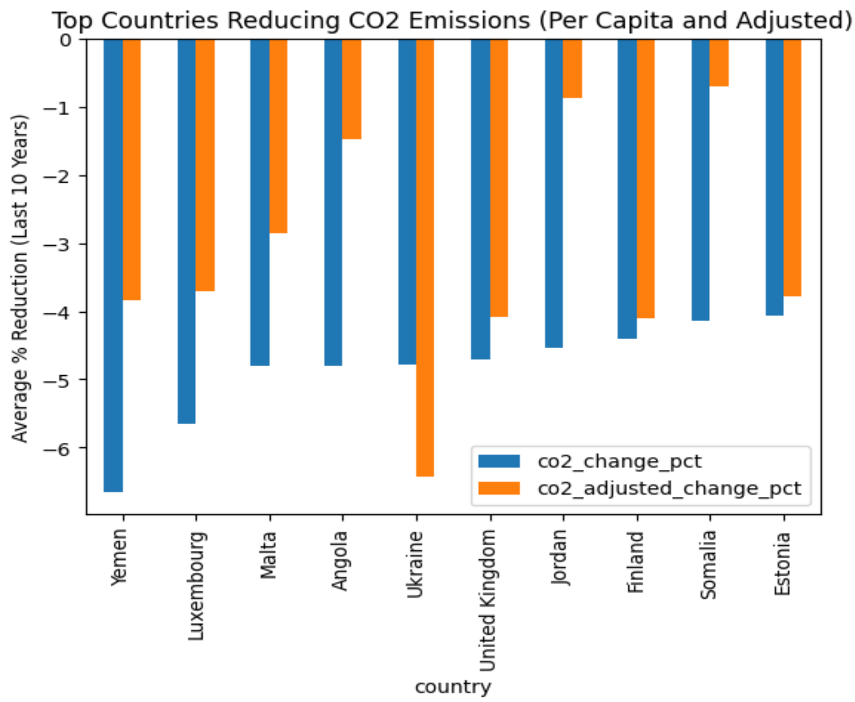
2.2.1 Methods

First the dataset containing annual CO2 emissions for each country was merged with the dataset containing population. Merging was done on the columns 'years' and 'country'. To identify countries that are making the biggest strides in reducing CO_2 emissions we focused on the years 2023 and 10 years before 2023 so 2013, since data from earlier years might not be directly related to current efforts to reduce CO_2 emissions. We calculated the relative CO2 emission reduction by computing the difference in CO_2 per capita between 2023 and 2013 for each country divided by the value of 2013 times 100 to make percentages of it. After that population data was used to account for the impact of growing and shrinking populations by multiplying CO2 per capita by the population size to estimate the total CO2 emissions relative to the population trend. Countries were then sorted by the magnitude of reduction to highlight leaders in emission cuts. A bar chart was made that shows the top 10 countries making the biggest strides to reduce CO2 and population adjusted values are also plotted.

2.2.2 Analysis

Figure 4 shows the bar chart of the top 10 countries making the biggest strides in reducing CO2 output and the population adjusted reductions (orange bars). Leaders in emission reductions (population adjusted) are Ukraine, Finland, United Kingdom, Yemen and Estonia.

Figure 4: Top 10 Countries achieving the greatest reductions in CO2 emissions per capita



2.2.3 Conclusion

Many European countries (e.g., Ukraine, Finland, United Kingdom) show significant declines in CO_2 emissions. From 2013 to 2023 Ukraine has made the biggest reductions in CO_2 emissions when taking changes in population into account.

2.3 Research question 3: Which non-fossil fuel will have the best price in the future?

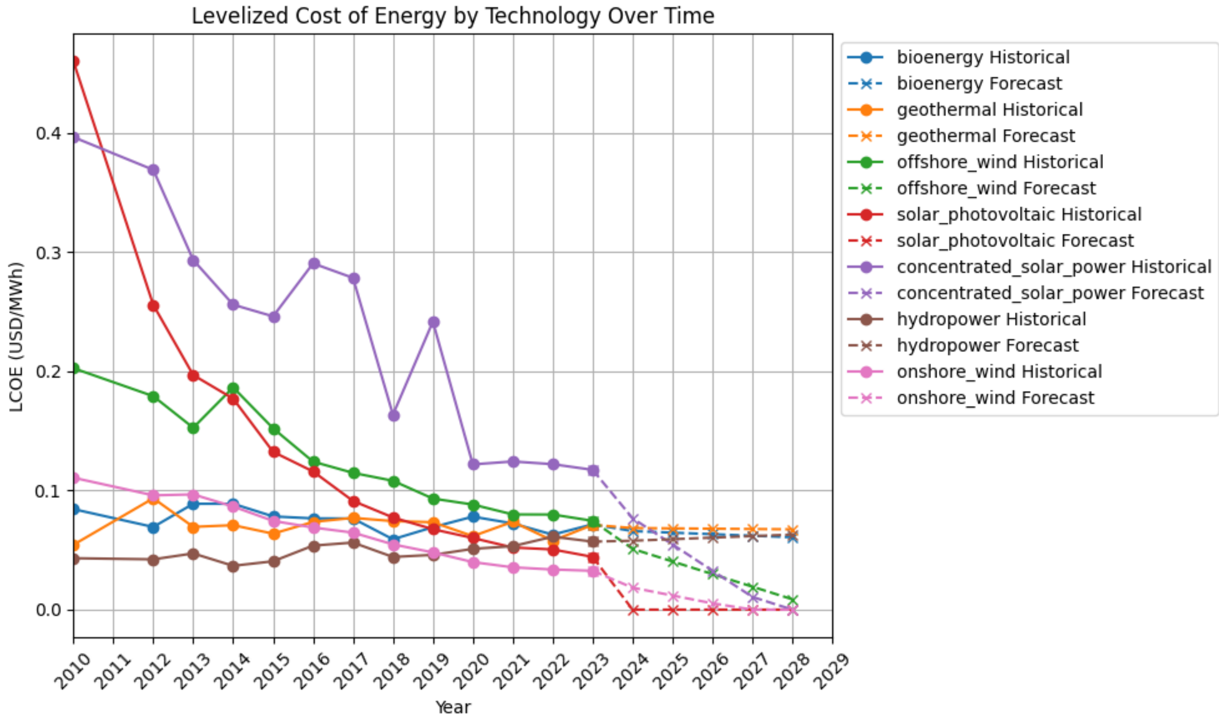
2.3.1 Methods

First, we used line plots to visualize the cost trends of non-fossil fuel energy technologies (e.g., solar, wind etc) from 2010 till 2023 for each technology. Then we predicted which technology will have the lowest costs in the future using a linear regression model based on historical cost trend data. Energy prices are expressed in 'levelized costs of energy' (LCOE) to make comparisons on a consistent basis. A lowest limit of 0.0 was set for LCOE predictions.

2.3.2 Analysis

Figure 5 shows the line plot of the cost trends of non-fossil fuel energy technologies over time together with the prediction of prices for the future (dashed lines). Solar energy (photovoltaic) shows the steepest decline in costs (fastest to zero). Wind energy continues to decrease but at a slower rate than solar energy. Costs of hydropower, geothermal energy and bioenergy remain relatively stable, with limited scope for significant reductions.

Figure 5: Levelized cost of energy by technology over time and future predictions



2.3.3 Conclusion

Solar photovoltaic energy is anticipated to have the lowest price in the future.

3. Conclusions

- Question 1: Economic output (GDP per capita) and energy per capita are the most significant predictors of large CO_2 emissions per capita, highlighting the challenges faced by developed countries in reducing emissions.

- Question 2: European countries lead the way in reducing CO_2 emissions, reflecting the impact of policy measures and renewable energy investments.

- Question 3: Solar energy is projected to become the most cost-effective non-fossil fuel technology, with significant implications for global energy policy.

4. Appendices

Google Colaboratory Python code
https://colab.research.google.com/drive/1N_WpyMao4ZzuW_Y4IbOq9iMRq3hfYrd1?usp=sharing
Data Per Capita CO2 emissions: https://ourworldindata.org/grapher/co-emissions-per-capita
Data Annual CO2 emissions: https://ourworldindata.org/grapher/annual-co2-emissions-per-country
Data non-fossil fuel energy: https://ourworldindata.org/grapher/levelized-cost-of-energy
CO2 and greenhouse gas emission: https://ourworldindata.org/co2-and-greenhouse-gas-emissions