# $CO_2$ emissions

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**Date:** March 25, 2024

## 1. Overview

Carbon dioxide ($CO_2$) is a major greenhouse gas that plays a crucial role in trapping heat in the earth's atmosphere, thereby contributing to climate change. It is emitted into the air through the burning of fossil fuels (such as coal, oil and natural gas), wildfires, and natural events like volcanic eruptions. Over the past few centuries, human activity has led to a 50% increase in atmospheric $CO_2$ levels. Since 2002, the amount of $CO_2$ has risen from 365 parts per million (ppm) to over 420 ppm today, a 15% increase. This growth is primarily caused by fossil fuel burning *(NASA, 2024)*.

In this report, some questions regarding $CO_2$ output will be analyzed and answered. The following questions and conclusions will be described:

1. **What is the biggest predictor of a large $CO_2$ output per capita of a country?**

   Out of 10 different possible predictors researched, the biggest predictors of a large $CO_2$ output per capita of a country are: GDP per capita, transport and human capital.

2. **Which countries are making the biggest strides in decreasing $CO_2$ output?**

   Curacao seems to be making the biggest strides in decreasing $CO_2$ output. Additionally, Macao and Venezuela are at the top of the list of countries that 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?**

   Concentrated solar power, solar photovoltaic, and onshore wind will possibly have the best price in the future.

Answering these questions will provide a starting point for further research to make better decisions to reduce $CO_2$ emissions in the future.

First in the '[Analysis'](#) section, the used methods, analysis, and conclusions will be described for each question. Following this, the '[Conclusion'](#) section will then discuss the conclusions and provide points for further research. After this in the '[Appendix'](#) section, the notebooks with the created code and data sources, and the used sources and can be found for further reference.

# 2. Analysis

In this chapter, the used methods, analysis, and conclusions will be described for each question.

## 2.1 Biggest predictor of $CO_2$ output

In this paragraph, the following question will be analyzed:

**What is the biggest predictor of a large $CO_2$ output per capita of a country?**

### 2.1.1 Methods

To research this question, first the following question has been answered: *What are factors that possibly predict large $CO_2$ output?* This has been researched by looking at various scientific studies about the subject. This led to a list of factors that are possible predictors. Out of this list, ten predictors have been chosen for further research. Criteria in choosing those possible predictors was that useful data was available. This led to the following ten possible predictors:

- Electricity consumption from fossil fuels, nuclear and renewables;
- GDP per capita;
- Urbanization rate;
- Human capital;
- Trade activities;
- Deforestation;
- Oil production;
- Aviation;
- Transport;
- Amount of livestock.

For each possible predictor, a dataset has been used that contains data about the possible predictor for each country and year.

With these datasets, for each possible predictor a scatterplot has been made with a linear regression line to find out whether there is a relation between the possible predictor and the $CO_2$ output per capita and how strong that relationship is. Also, for each possible predictor the correlation between the possible predictor and the $CO_2$ output per capita of a country has been calculated.

More in-depth details about the method, used data, created graphs and calculated correlations for this question can be found in notebook 1.

### 2.1.2 Analysis

In this paragraph, the scatterplots of the three possible predictors that are the biggest predictors will be shown and described.

**GDP per capita**

*Figure 1* shows a scatter chart of the GDP per capita versus the amount of $CO_2$ emissions per capita. The graph shows that the $CO_2$ emissions per head of capita raises with 2.3 tonnes per person for each $10.000 raise in GDP per capita. This raise is a significant relationship because the correlation is 0.7 ($p < 0.05$) which indicates there is a strong relation between GDP per capita and $CO_2$ emissions per capita.

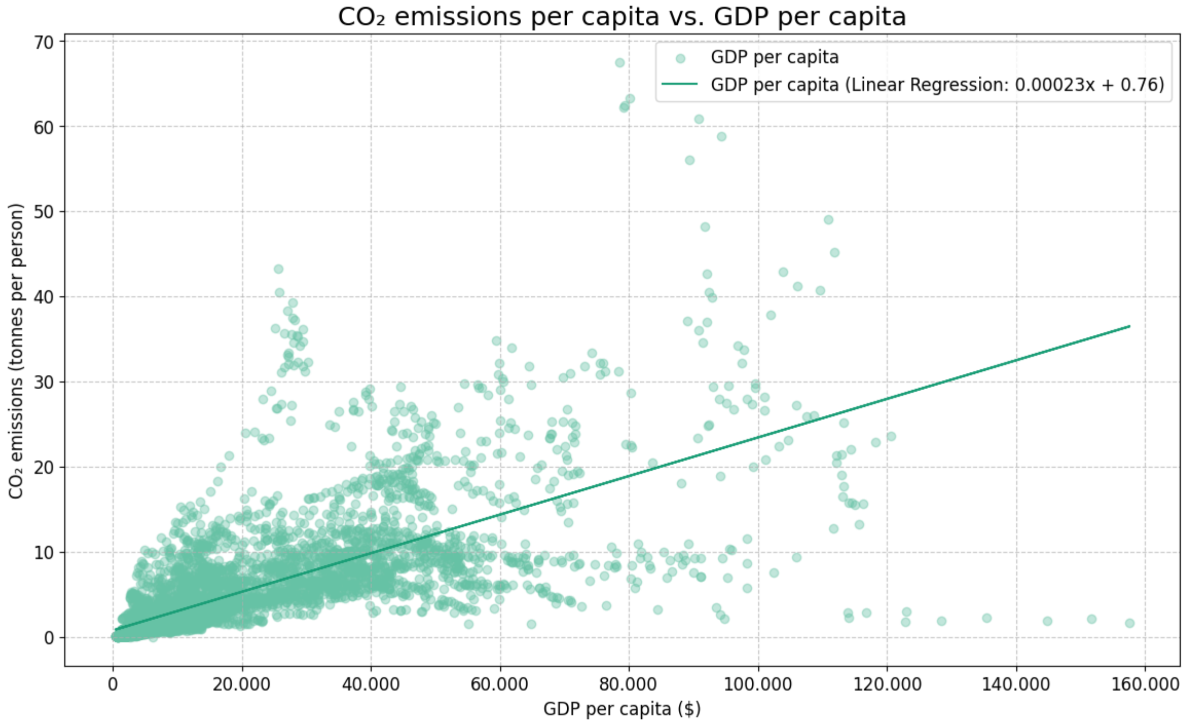


*Figure 1: $CO_2$ Emissions per capita vs. GDP per capita.*

**Transport**

There is a strong positive correlation between $CO_2$ emissions per capita from transportation and overall $CO_2$ emissions per capita (0.7, $p < 0.05$). The graph, which can be found in *Figure 2*, shows that for every ton of $CO_2$ emissions per person from transport, there is an increase of 3.57 tonnes in overall $CO_2$ emissions per capita. It's important to note that each ton of $CO_2$ emissions from transport contributes directly to the total $CO_2$ emissions per capita. When accounting for this, each ton of $CO_2$ emissions from transportation leads to an additional 2.57 tonnes of $CO_2$ emissions per capita.

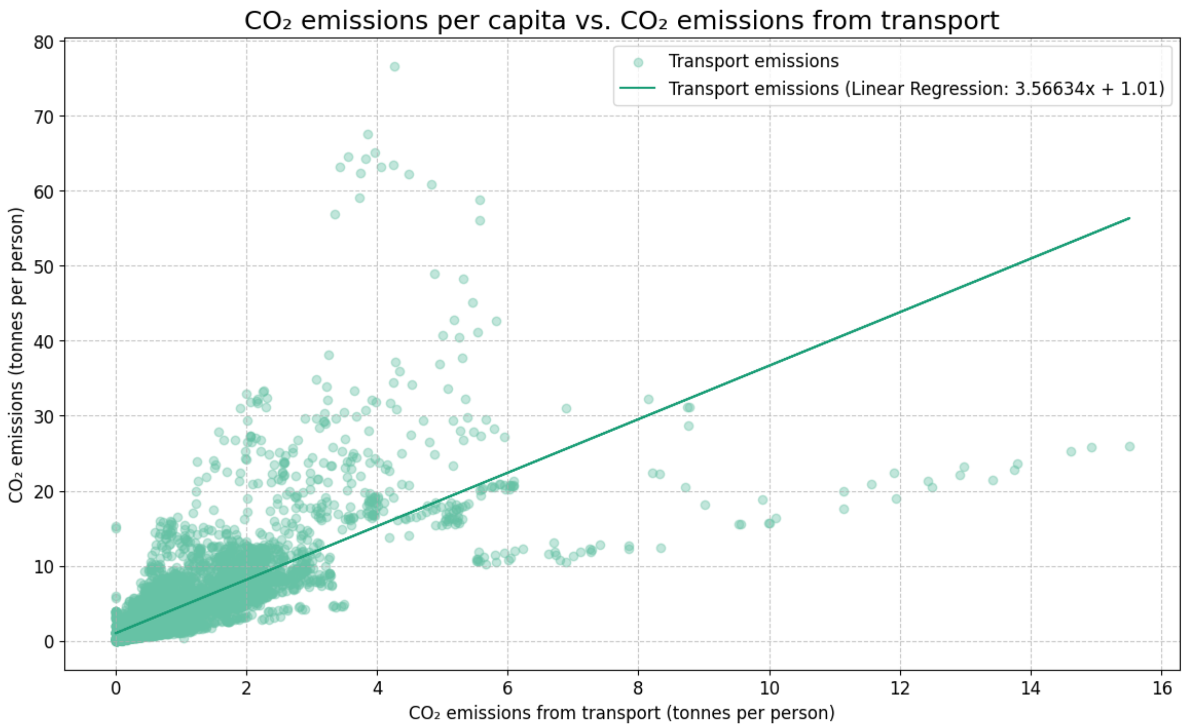


*Figure 2: $CO_2$ Emissions per capita vs. $CO_2$ emissions from transport.*

**Human Capital**

What exactly is 'Human Capital'? "*The Human Capital Index (HCI) combines indicators of health and education into a measure of the human capital that a child born today can expect to obtain by their 18th birthday, on a scale from 0 to 1. Higher values indicate higher expected human capital.*" (Our World in Data)

The graph, which can be found in *Figure 3*, shows that the Human Capital Index (HCI) has some influence on the $CO_2$ emissions per capita. When the HCI gets 0.1 higher, the $CO_2$ emission per capita of a country raises with 2.1 tonnes. The correlation supports there is a relation between HCI and $CO_2$ emissions per capita with a significant correlation of 0.5 ($p < 0.05$). However, this dataset has a lot less data than the datasets of the other factors, so that might bias the results.

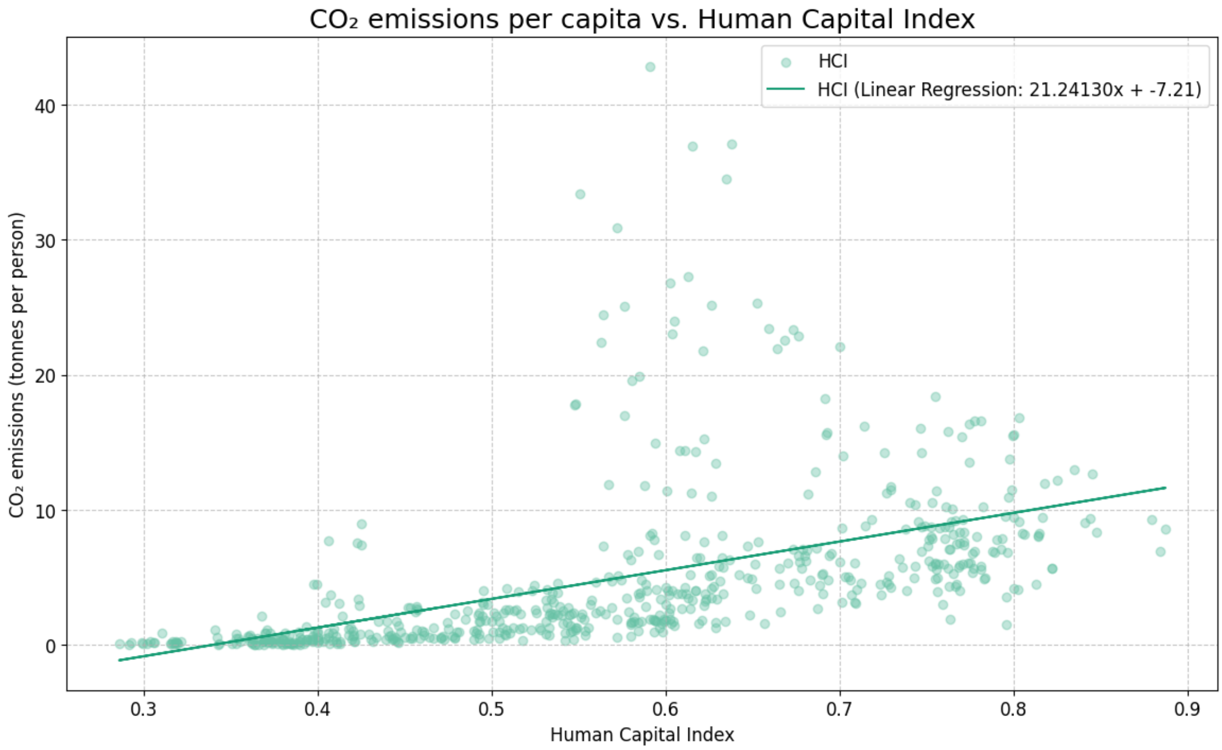


*Figure 3: $CO_2$ Emissions per capita vs. Human Capital Index.*

## 2.1.3 Conclusion

**What is the biggest predictor of a large $CO_2$ output per capita of a country?**

Out of the 10 different possible predictors researched, the following 3 predictors are the biggest:

- **GDP per capita**: with a correlation of 0.7 the GDP per capita causes an increase of 2.3 tonnes per head of capita for each $10.000 raise in GDP per capita.
- **Transport**: There is a correlation of 0.7 between transportation and $CO_2$ emissions per head of capita. Every ton of $CO_2$ emissions from transport leads to 2.57 extra tonnes of $CO_2$ emissions per capita.
- **Human Capital Index (HCI)**: With a correlation of 0.5, the HCI could be a big predictor of $CO_2$ output, with the $CO_2$ emission per capita raising with 2.1 tonnes when the HCI raises with 0.1. However, this is only supported by a small amount of data.

There could, however, be additional big predictors of $CO_2$ output that have not been explored in this analysis.

## 2.2 Biggest strides in decreasing $CO_2$ output

In this paragraph, the following question will be analyzed:

**Which countries are making the biggest strides in decreasing $CO_2$ output?**

### 2.2.1 Methods

To answer this question, it was decided to focus on the time period from 2016 until 2022, following the UN Climate Change Conference (COP21) in Paris in December 2015. There, world leaders set an agreement known as The Paris Agreement to reduce global greenhouse gas emissions *(United Nations, n.d.)*. It would be expected that countries are actively reducing $CO_2$ emissions since then. For 2023, there was no data available yet.

The question has been researched in two ways:

- Per capita percentage change in $CO_2$ emissions: This approach considers the percentage of change in $CO_2$ emissions per capita, accounting for fluctuating population size which makes it a good approach to make comparisons between countries. For this approach, a dataset was used that contains the annual $CO_2$ emissions per capita of a country for all years.
- Percentage change in total $CO_2$ emissions: This approach identifies countries that are making the biggest improvements in total $CO_2$ output, regardless of population or country size. For this approach, a dataset was used that contains the total annual $CO_2$ emissions per country for all years.

For both approaches, two analyses have been done:

- The $CO_2$ emissions (per capita or in total) for each country in 2022 was compared to the $CO_2$ emissions (per capita or in total) for each country in 2016. This led to a percentage increase or reduction for each country.
- The $CO_2$ emissions (per capita or in total) of each year for each country were compared to the $CO_2$ emissions (per capita or in total) of the previous year. This led to a percentage change (increase or decrease) for each year compared to the previous year. Then, the average percentage change (increase or decrease) in $CO_2$ emissions (per capita or in total) over the years 2016 until 2022 was calculated.

More in-depth details about the method, used data and created graphs for this question can be found in notebook 2.

### 2.2.2 Analysis

In this paragraph, the graphs that have been created to analyze the question will be shown and described.

**Per capita percentage change in $CO_2$ emissions**

*Figure 4* shows the top 10 countries that have had the biggest percentage decrease in $CO_2$ emissions per capita in 2022 compared to 2016. The top 3 countries that decreased $CO_2$ emission per capita the most are Curacao, Macao and Venezuela.

*Figure 5* shows the top 10 countries where the average yearly decrease in $CO_2$ emission per capita over the years 2016-2022 was the highest. Despite fluctuations in yearly emissions, the top 3 countries that have consistently reduced their $CO_2$ emissions on average when each year is compared to the previous year between the years 2016 and 2022 are Curacao, Angola and Montserrat.

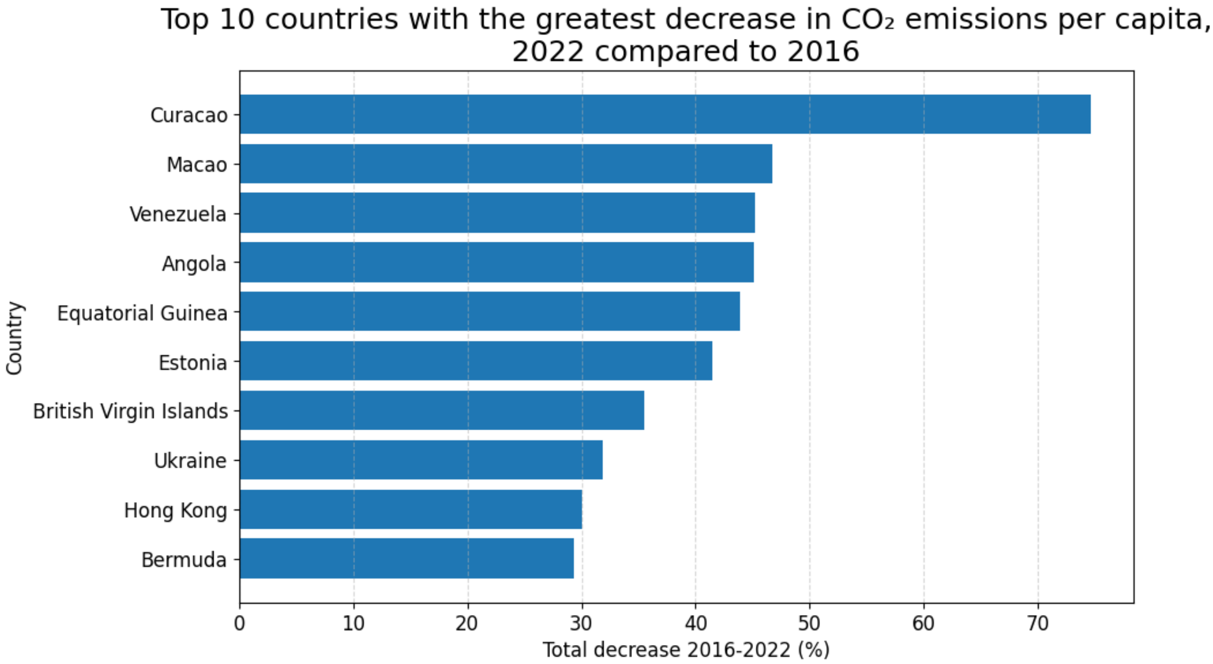


*Figure 4: Top 10 countries with the greatest decrease in $CO_2$ emissions per capita in 2022 compared to 2016.*

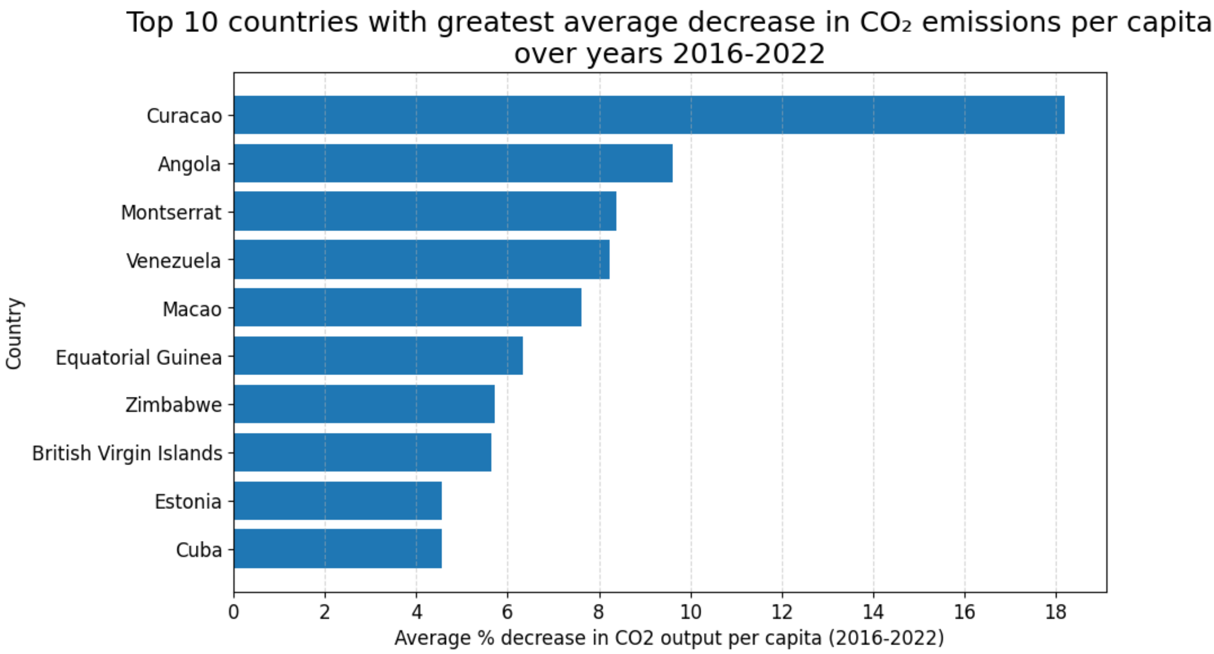


*Figure 5: Top 10 countries with the greatest average decrease in $CO_2$ emissions per capita over years 2016-2022.*

**Percentage change in total $CO_2$ emissions**

*Figure 6* shows the top 10 countries that have had the biggest decrease in total $CO_2$ emissions in 2022 compared to 2016. The top 3 countries that decreased the total $CO_2$ emissions the most in the year 2022 compared to 2016 are Curacao, Venezuela, and Estonia.

Despite fluctuations in yearly emissions, the top 3 countries that have consistently reduced their total $CO_2$ emissions on average when each year is compared to the previous year between the years 2016 and 2022 are Curacao, Montserrat, and Venezuela, as is shown in *figure 7*.

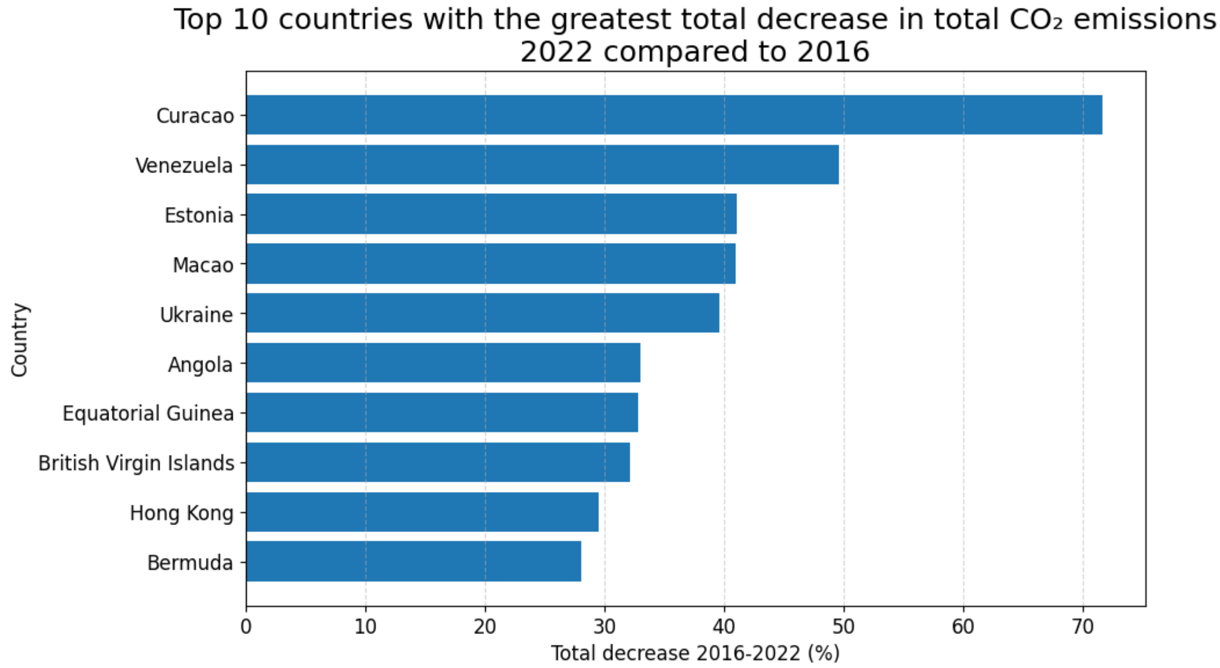


*Figure 6: Top 10 countries with the greatest total decrease in total $CO_2$ emissions in 2022 compared to 2016.*

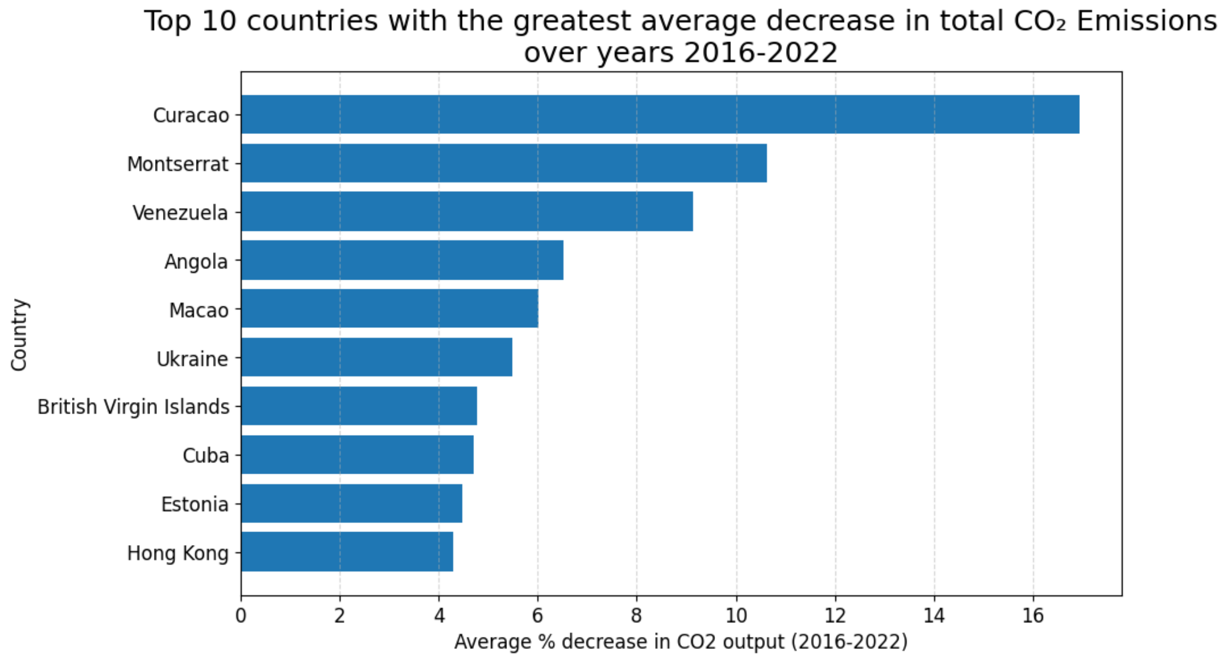


*Figure 7: Top 10 countries with the greatest average decrease in total $CO_2$ emissions over years 2016-2022.*

### 2.2.3 Conclusion

**Which countries are making the biggest strides in decreasing $CO_2$ output?**

In all approaches to analyzing this question, Curacao seems to be making the biggest strides in decreasing $CO_2$ output, both per capita and in total. Additionally, Macao and Venezuela are in the top 5 of each graph, putting them also at the top of the list of countries that are making the biggest strides in decreasing $CO_2$ output. Other countries that show up in each top 10 and are therefore making big strides are Estonia and British Virgin Islands. Other countries that are worth mentioning in decreasing $CO_2$ output that show up in the top 10 of one or more graphs are Angola, Bermuda, Cuba, Equatorial Guinea, Hong Kong, Montserrat, Ukraine, and Zimbabwe.

## 2.3 Non-fossil fuel energy with best price in the future

In this paragraph, the following question will be analyzed:

**Which non-fossil fuel energy technology will have the best price in the future?**

### 2.3.1 Methods

To answer this question, a dataset was used that has the worldwide levelized cost of energy for each technology. The levelized cost is the cost per unit of energy generated across the lifetime of a new power plant *(Our World in Data, n.d.)*. For this analysis, it is assumed that energy prices follow the levelized costs; as it becomes cheaper to generate energy with a certain technology, consumer prices will also lower down.

The non-fossil fuel energy technologies that have been analyzed are: bioenergy, geothermal energy, offshore wind energy, onshore wind energy, solar photovoltaic energy, concentrated solar power and hydropower.

With the dataset, a scatterplot has been created that shows the cost of the various energy technologies over the years. A regression line and future years have been added to calculate the possible energy costs of the different technologies in the future.

More in depth details about the method, used data and created graphs for this question can be found in notebook 3.

### 2.3.2 Analysis

In this paragraph, the graph that has been created to analyze the question will be shown and described.

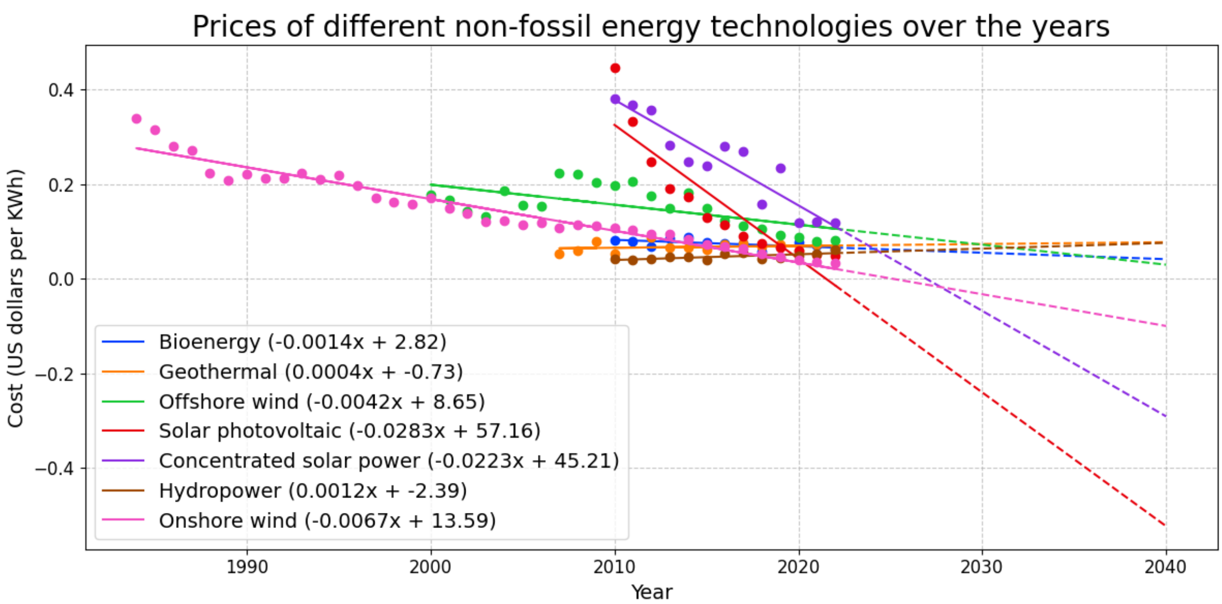


*Figure 8: Prices of different non-fossil fuel energy technologies over the years.*

The graph in figure 8 shows the following:

**Bioenergy, geothermal energy, and hydropower**

These three energy technologies start with relatively low levelized costs compared to others and seem to have relatively stable levelized costs over time, with minor fluctuations to be expected in the future. While the levelized cost of bioenergy might decrease slightly in the future, the levelized costs of geothermal and hydropower energy may experience slight increases.

**Onshore and offshore wind energy**

The levelized cost of onshore and offshore wind energy technologies show a clear downward trend, gradually decreasing over time.

**Concentrated solar power, and solar photovoltaic energy**

Both of the solar power technologies historically had higher levelized costs compared to the other technologies but have experienced a rapid decrease in costs. However, in recent years, the rate of this decrease has stabilized somewhat. Therefore, a future price/cost prediction must be made with caution.

### 2.3.3 Conclusion

**Which non-fossil fuel energy technology will have the best price in the future?**

The extrapolated regression lines shows that both solar technologies (Concentrated solar power and solar photovoltaic energy), as well as onshore wind, could potentially reach a negative cost in the future, and might thus become economically profitable and/or have the best price in the future. However, from 2020 to 2022, the levelized costs of all different energy technologies seem to stabilize around the current levels so this is not certain.

# 3. Conclusion

The questions analyzed in this report and their conclusions are as follows.

## 3.1 What is the biggest predictor of a large $CO_2$ output per capita of a country?

Out of the 10 different possible predictors researched, the following 3 predictors are the biggest:

- **GDP per capita**: With a correlation of 0.7 the GDP per capita causes an increase of 2.3 tonnes per head of capita for each $10.000 raise in GDP per capita.
- **Transport**: There is a correlation of 0.7 between transportation and $CO_2$ emissions per head of capita. Every ton of $CO_2$ emissions from transport leads to 2.57 extra tonnes of $CO_2$ emissions per capita.
- **Human Capital Index (HCI)**: With a correlation of 0.5, the HCI could be a big predictor of $CO_2$ output, with the $CO_2$ emission per capita raising with 2.1 tonnes when the HCI raises with 0.1. However, this is only supported by a small amount of data.

There could however be additional big predictors of $CO_2$ output that have not been explored in this analysis. Further research could focus on other predictors or multiple predictors at once (and their potential influence on each other). Also, it hasn't been analyzed *why* these factors are big predictors of a large $CO_2$ output and others are not so this could be interesting to find out.

## 3.2 Which countries are making the biggest strides in decreasing $CO_2$ output?

In all approaches to analyze this question, Curacao seems to be making the biggest strides in decreasing $CO_2$ output, as well as per capita as in total. Also Macao and Venezuela are in the top 5 of each graph, putting them also on top of the list of countries that are making the biggest strides in decreasing $CO_2$ output. Other countries that show up in each top 10 and therefore making big strides are Estonia and British Virgin Islands. Other countries that are worth mentioning in decreasing $CO_2$ output that show up in the top 10 of one or more graphs are Angola, Bermuda, Cuba, Equatorial Guinea, Hong Kong, Montserrat, Ukraine and Zimbabwe.

Now the countries that are making the biggest strides in decreasing $CO_2$ output are identified, it could be interesting to research for what reason these countries are making the biggest strides. Are they making the conscious decision to decrease the $CO_2$ output, or has there possibly been a change in one of the predictors that have been found in question 1 (GDP per capita, transport or HCI) for that country?

## 3.3 Which non-fossil fuel energy technology will have the best price in the future?

Concentrated solar power, solar photovoltaic energy and onshore wind could potentially reach a cost below zero in the future, and might thus become economically profitable and/or have the best price in the future. However, from 2020 to 2022, the levelized costs of all different energy technologies seem to stabilize around the current levels so this is not certain. Monitoring the costs over the next few years would provide insight into whether the stabilization of the costs continues.

Additionally, external factors such as technological improvements, economic or political changes, may influence energy costs and prices, factors that haven't been researched in this analysis.

# 4. Appendix

## 4.1 Notebooks

For this analysis, three notebooks have been created, which can be found on the following links:

Notebook 1, Biggest predictor of $CO_2$ output:
https://colab.research.google.com/drive/1HBFvNeLvmNQdOzAHJ3-4YCSTGDJtebOl?usp=sharing

Notebook 2, Biggest strides in decreasing $CO_2$ output:
https://colab.research.google.com/drive/1A43BusSzR3K9Xo8D6CaRIW8vUgzJKYIn?usp=sharing

Notebook 3, Non-fossil fuel energy with best price in the future:
https://colab.research.google.com/drive/1EYcyc8JXK0_2-oVucGuyXpgp3pRddrU6?usp=sharing

The sources of the used data are linked in the notebooks.

## 4.2 Sources


NASA. (2024, january). *Carbon Dioxide*. Retrieved from NASA: https://climate.nasa.gov/vital-signs/carbon-dioxide/

Our World in Data. (n.d.). Retrieved from Our World in Data: https://ourworldindata.org/grapher/human-capital-index-in-2018

Our World in Data. (n.d.). *Levelized cost of energy by technology*. Retrieved from https://ourworldindata.org/grapher/levelized-cost-of-energy

United Nations. (n.d.). *The Paris Agreement*. Retrieved from https://www.un.org/en/climatechange/paris-agreement