CO_2 EMISSIONS & HUMAN BEHAVIOUR

Data Analysis with Python

final assignment Winc Academy

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CO_2 EMISSIONS & HUMAN BEHAVIOUR

INTRODUCTION

This report is the final assignment of the online course 'Data Analytics with Python' (Winc Academy).

FINAL ASSIGNMENT

The final assignment consists of three subassignments around CO_2 emissions. These subassignments will be answered using the techniques around analyzing data with Python learned during the course at Winc Academy. Text and visualizations will show the result of the analyses. The given data source is the website of Our World in Data[1].

The three subassignments are about finding:

1. the biggest predictor of CO_2 output;
2. the biggest strides in decreasing CO_2 output;
3. the best future price for nonfossil fuel energy.

CO_2 & HUMAN BEHAVIOUR

CO_2 produced by human activities is the largest contributor to global warming. As we can influence our behaviour visualizing the impact of our behaviour through data can help raising awareness and can show what we as individuals can do to reduce global warming.

[1] Our World in Data (OWID) is a scientific online publication that focuses on large global problems such as poverty, disease, hunger, climate change, war, existential risks, and inequality.

Before showing the results of the analyses around CO_2 emissions a useful model is introduced. The Japanese energy economist Yoichi Kaya invented a mathematical model that allows us to understand the relation between CO_2 emissions and human activities. It's called the Kaya Identity and was introduced in 1993 in Kaya's book 'Environment, Energy and Economy: strategies for sustainability'.

With the model Kaya explains that the total emission of the greenhouse gas carbon dioxide can be expressed as the product of four factors:

1. human population
2. income (GDP/population or GDP per capita)
3. energy intensity (energy per unit of GDP)
4. carbon intensity (emissions per unit of energy consumed)

In figure 1 the mathematical model 'Kaya Identity' is clearly visualized by Our World in Data. It shows the four key elements of human impact on climate, CO_2 emissions to be specific:

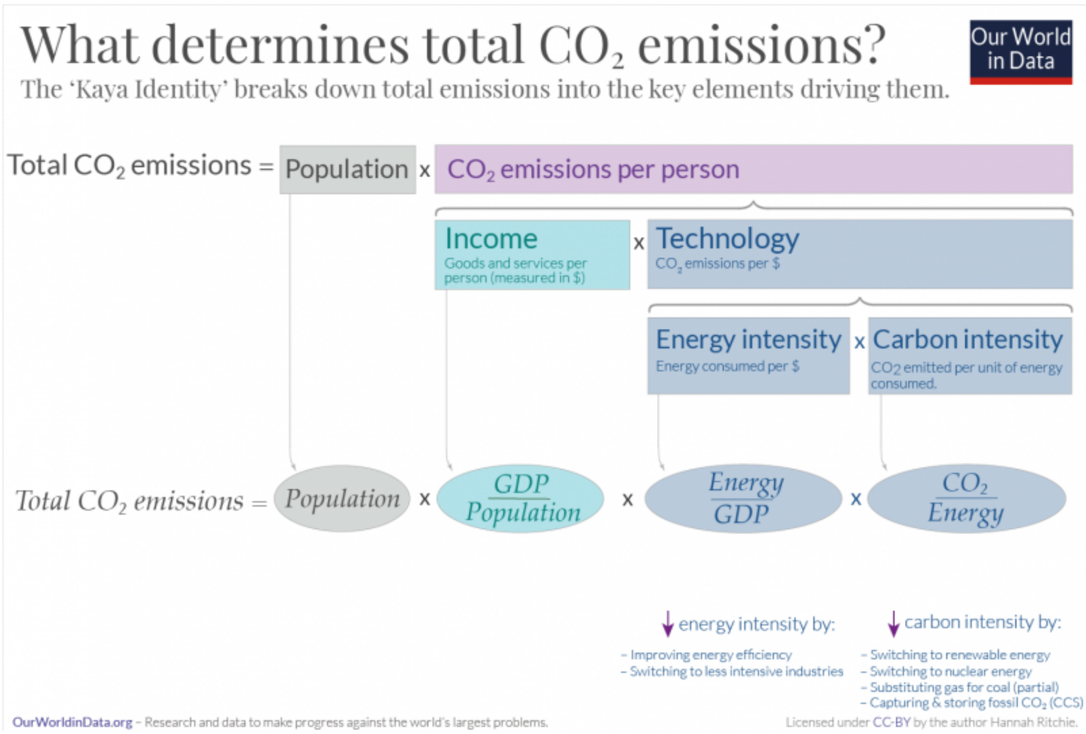

Figure 1 Kaya Identity visualized by Our World in Data.

This report contains four chapters. Chapter 1 will reveal what the biggest predictor of a large CO_2 output per capita of a country is (data analysis 1). Chapter 2 will show which countries are making the biggest strides in decreasing CO_2 output (data analysis 2). Chapter 3 shows an indication of which nonfossil energy technology will have the best price in the future (data analysis 3). The last chapter will be a summary of the results.

Trust this report will proof to be an interesting read, looking at the visualizations and who knows if the results shown will give a new perspective on small or big changes we can make now that can have a positive impact on the climate.

"Data isn't units of information.

Data is a story about human behaviour - about real people's wants, needs, goals and fears.

Never let the numbers, platforms ans methodologies cloud your vision. Our real job with data is to better understand these very human stories, so we can better serve these people."

Daniel Burstein

DATA ANALYSIS 1.

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

This chapter will reveal what can predict a large CO_2 output per person (= per capita). As mentioned in the introduction, CO_2 produced by human activities is the largest contributor to global warming. So understanding what can predict a large CO_2 output can help us in revealing the key elements that we can influence in the (near) future. Data can show what has happened in the past and what has to change over time to reach a target level of CO_2 emissions in the future.

The Kaya Identity shows that the CO_2 output per person is the product of Income and Technology (figure 2). Income is considered as goods and services per person measured per dollar. Technology is the CO_2 output per dollar spent.

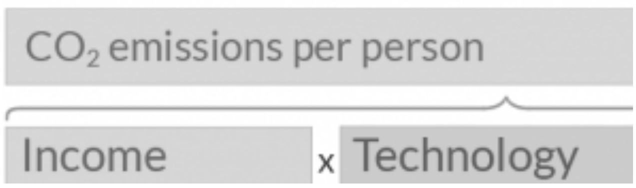

Figure 2 Part of the Kaya Identity model

So if the CO_2 output per person is determined by Income and Technology, which one is the most significant until now? Let's first look at Income and Technology separately.

INCOME

For the influence of income on CO_2 emissions we can look at the data of the GDP per person (capita). According to Our World in Data data shows that most countries have had a large increase of GDP per capita (income) in the last decades. And that there is a very strong correlation between CO_2 emissions and income. See figure 3[2]:

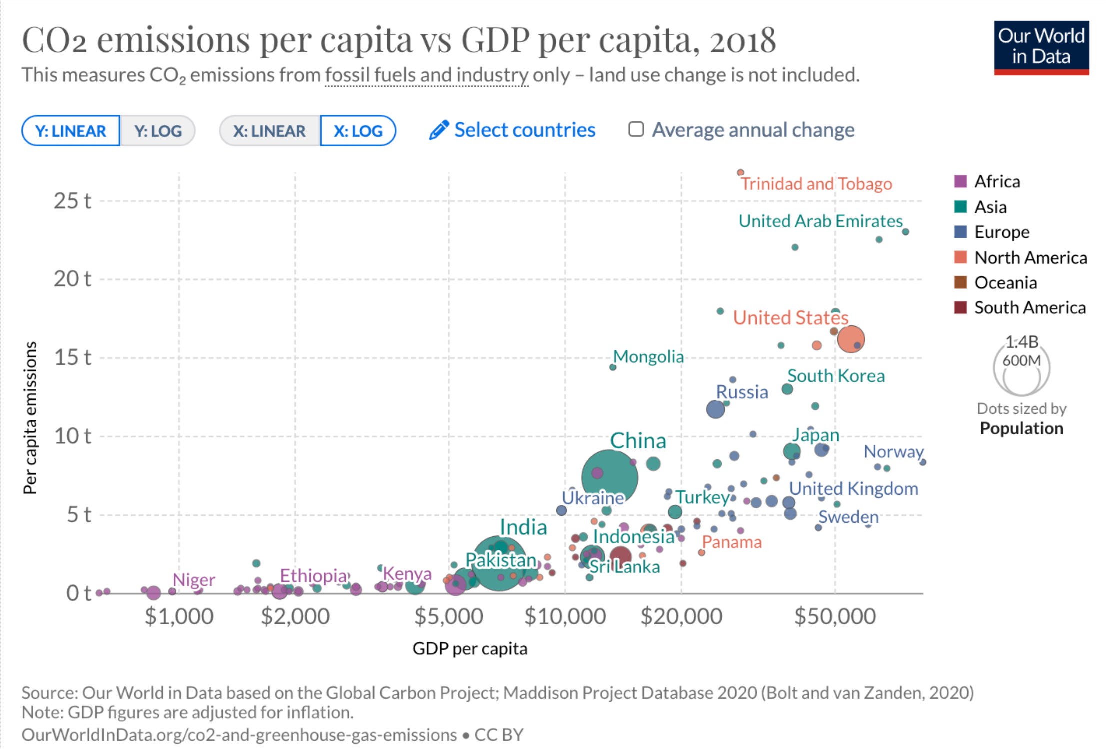

Figure 3 CO_2 output per capita versus GDP per capita (2018), Our World in Data

Richer people tend to emit more CO_2 according to Our World in Data[3]. As we get richer we gain access to and increase our consumption of electricity, heating, transport and other goods that require energy inputs. The strong reliance on fossil fuels until now resulted in an increase in CO_2 emissions.

Furthermore Our World in Data has investigated that CO_2 emissions are closely linked to economic growth because we clearly see the impacts of large economic shocks on annual emissions. See figure 4. Globally and across countries trends do not completeley match according to Our World in Data[4]. This means there are additional influences - changes in industrial activities, efficiency and fuel mix (energy and carbon intensity) - at play.

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[2] Other data show that CO_2 emissions due to land use change is insignificant compared to CO2 emissions from fossil energy and industry. https://ourworldindata.org/co2-emissions#global-co2-emissions-from-fossil-fuels-and-land-use-change
[3] https://ourworldindata.org/emissions-drivers#richer-people-emit-more-co2
[4] https://ourworldindata.org/emissions-drivers#co2-emissions-are-sensitive-to-economic-shocks

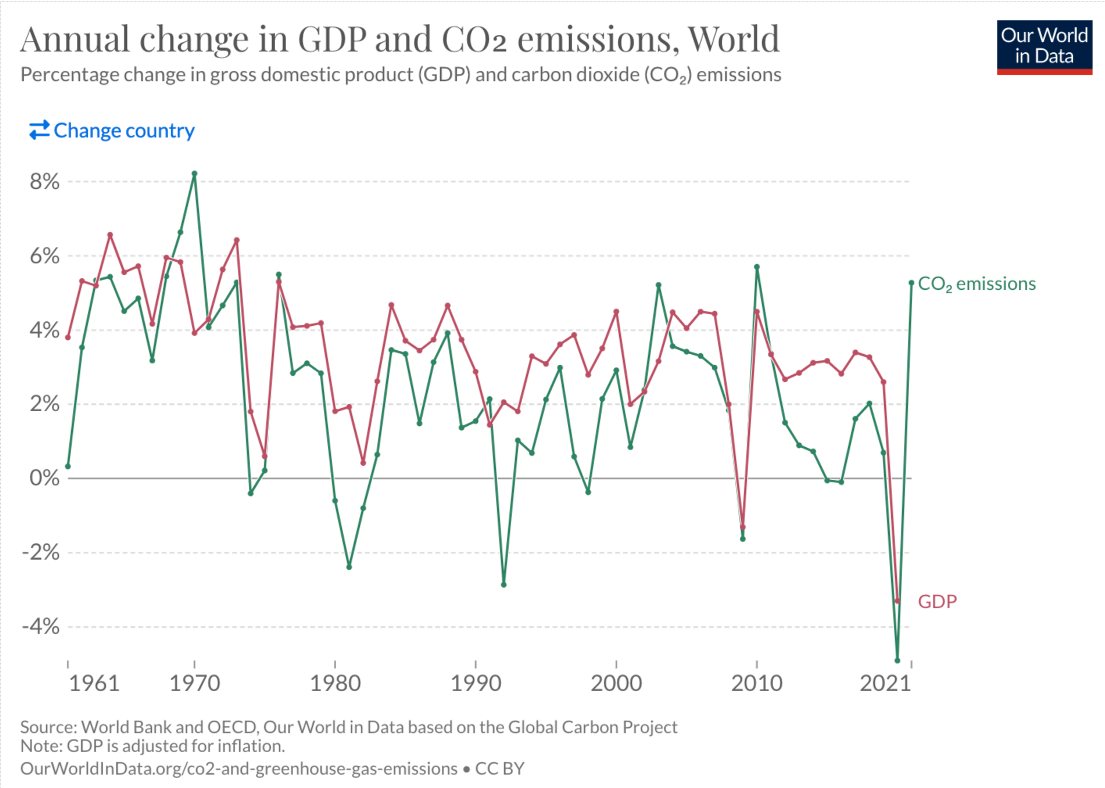

Figure 4 Annual change in GDP and CO_2 output, Our World in Data

Conclusion: income tends to influence CO_2 output per person and is taken into account in this analysis.

TECHNOLOGY

For the impact of technology on CO_2 emissions we look at the two dimensions it contains according to the Kaya Identity:

a. *Energy intensity: amount of energy consumed per unit of GDP*
b. *Carbon intensity: amount of CO_2 emitter per unit of energy*

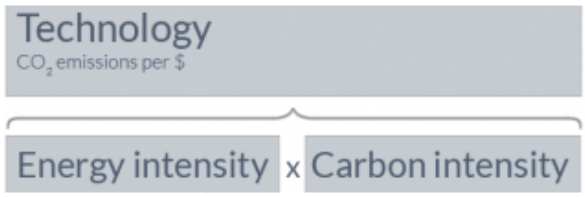

Figure 5 Technology in the Kaya Identity

Let's explore Energy intensity and Carbon intensity.

Technology: Energy intensity

Energy intensity reflects how energy-efficient an economy is. A lower Energy intensity means it can generate more value added, with fewer energy inputs. Global energy intensity decreased by nearly one-third between 1990 and 2015. See figure 6:

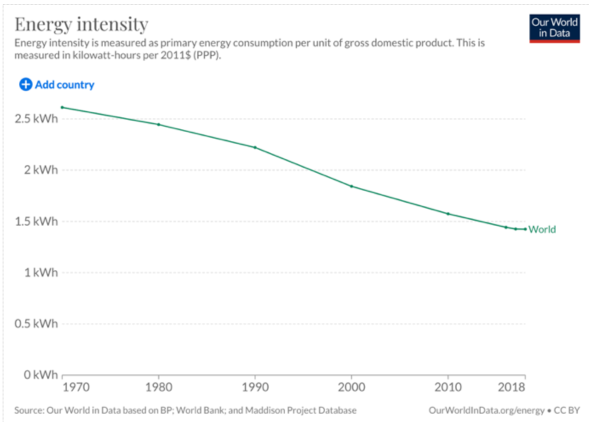

Figure 6 Energy intensity between 1990 and 2015, Our World in Data

Technology: Carbon intensity

Carbon intensity reflects how clean, low- or high-carbon, the energy mix is. Renewable energy sources e.g. have a lower carbon intensity than fossil fuels (measured on a total life cycle basis). Global Carbon intensity has trended downwards since 1965.[5] See figure 7:

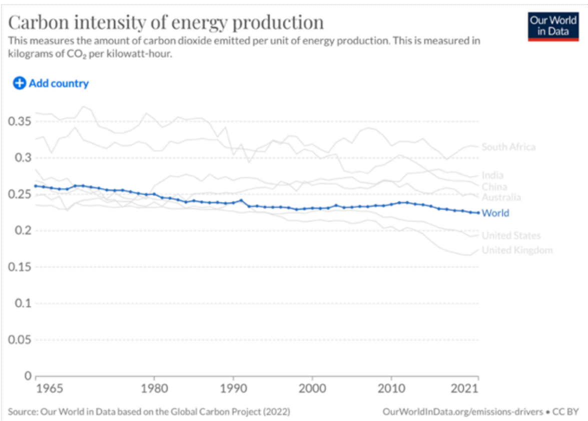

Figure 7 Carbon intensity of energy production, Our World in Data

The carbon intensity is strongly dependent on how much fossil fuels are included in the energy mix relative to low-carbon sources. A country would have a lower carbon intensity if its energy mix was dominated by gas as opposed to coal - per unit of energy gas usually produces less CO_2.

Conclusion: Technology is defined by energy intensity (how efficient the energy is) and carbon intensity (how clean the energy is). Both have an impact on CO_2 output per person and are therefore part of the analysis.

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5 https://www.actuaries.org.uk/system/files/field/document/Kaya%20identity_JC%20Final%20050219.pdf#:~:text=In%20order%20for%20Global%20CO2,Energy%20Intensity%20can%20be%20zero.

DATA ANALYSIS DRIVERS CO_2 OUTPUT PER CAPITA

The goal of this data analysis is to find the biggest predictor of a large CO_2 output per capita of a country.

CO_2 output per capita

If we use the Kaya Identity (CO_2 = Population x Income x Technology) we can easily rebuild the model to find the drivers for CO_2 output per capita:

CO_2 output per capita = Income x Technology

The previous paragraphs have shown that both Income and Technology have substantial impact and should be taken into account in further analysis. This further analysis focuses on the following relationships:
CO_2 output per capita per country versus:

- *Income (= GDP per capita)*
- *Technology (= energy intensity x carbon intensity):*
  - *energy intensity (how efficient is energy produced?)*
  - *carbon intensity (how clean is the energy mix?)*

To calculate how strong the correlation is between these factors and the CO_2 output per capita we look at the correlation coefficient according to the Pearson method.

Which countries have the largest CO_2 output per capita?

First, let's see which countries in the world have the largest CO_2 output per capita. Figure 8 shows the top 35 countries worldwide with the largest CO_2 output per capita in 2018[6]:

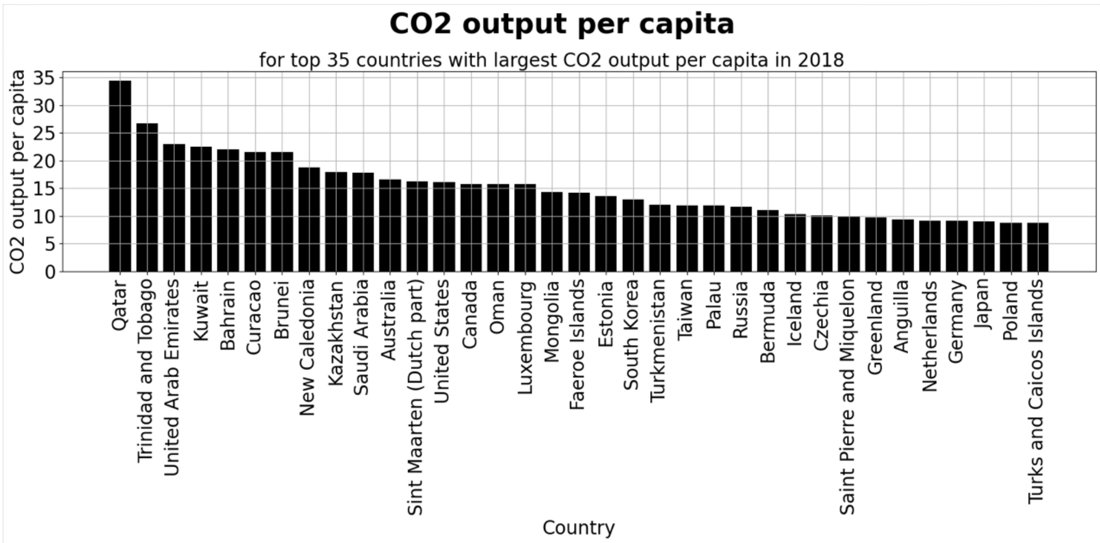

Figure 8 Countries worldwide with the largest CO2 output per capita (2018)

[6] 2018 is the most recent year with complete data for all components of the Kaya Identity

In 2018 Qatar has the largest CO_2 output per capita, followed by Trinidad and Tobago and the United Arab Emirates. The Netherlands is at position 31, just before Germany.

For the years 2019, 2020 and 2021 (figure 9) the data is not complete for Income and Technology but the CO_2 output per capita is known. The top 5 is quite constant. Qatar stays number 1, and the following countries seem to change position but stay in the top 5. The exception is United Arab Emirates which changes place with Brunei.

World's largest emitters of CO_2 per capita (2018-2021)				
	2018	*2019*	*2020*	*2021*
1	***Qatar***	***Qatar***	***Qatar***	***Qatar***
2	*Trinidad and Tobago*	*Trinidad and Tobago*	*Bahrain*	*Bahrain*
3	*United Arab Emirates*	*Bahrain*	*Brunei*	*Kuwait*
4	*Kuwait*	*Brunei*	*Trinidad and Tobago*	*Trinidad and Tobago*
5	*Bahrain*	*Kuwait*	*Kuwait*	*Brunei*
6	*Curacao*	*United Arab Emirates*	*United Arab Emirates*	*United Arab Emirates*

Figure 9 World's largest emitters of CO2 per capita, 2018-2021

CO_2 output per capita and its main drivers

Now let's zoom in at the main drivers that form the CO_2 output per capita, Income and Technology.

CO_2 output per capita = Income x Technology

Is there a clear relationship between the top 35 countries with the largest CO_2 output per capita and their Income (GDP per capita)? See figure 10.

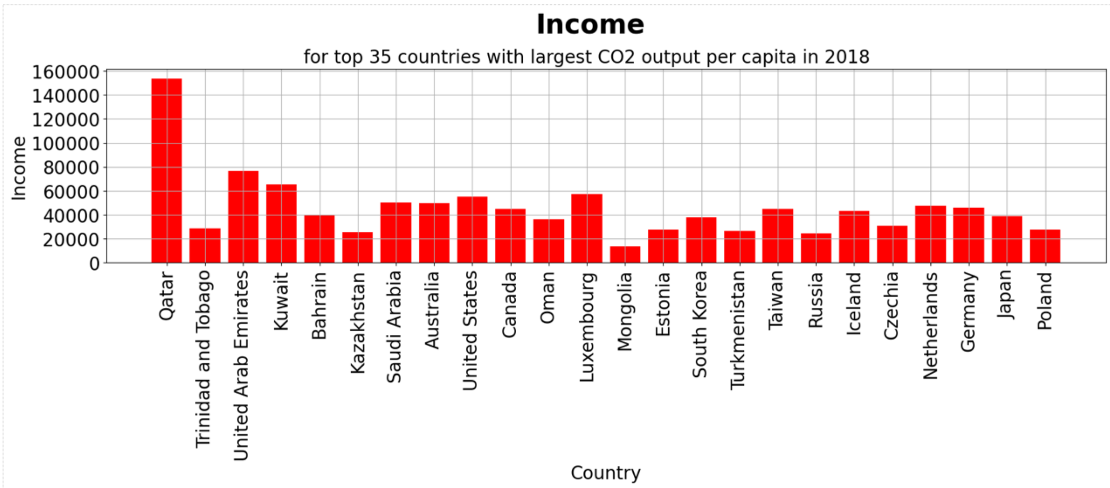

Figure 10 Income for top 35 countries with largest CO2 output per capita in 2018

Qatar clearly stands out in Income and CO_2 output per capita. The results for Technology are different. See figure 11. There, Trinidad and Tobago (nr. 2 largest emitter) and Mongolia (nr. 13 largest emitter) stand out.

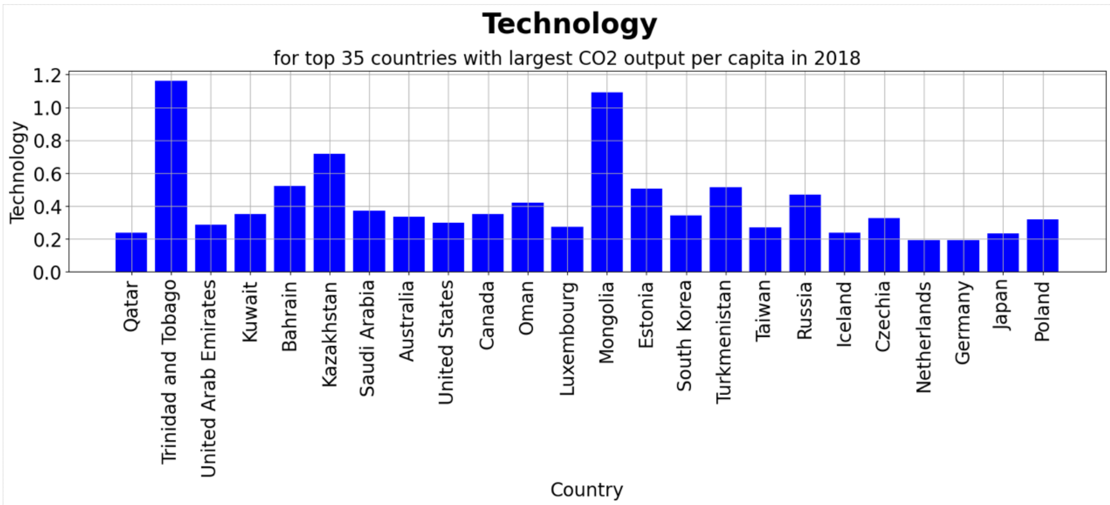

Figure 11 Technology for top 35 countries with largest CO2 output/capita in 2018

Let's analyze this further.

Correlation between CO_2 output per capita and main drivers

We can compare the relationship between CO_2 output per capita and Income and Technology by applying the Pearson method for correlation. A correlation coefficient of more than 0.5 or less than -0.5 indicates a strong relationship between two elements.

Does the correlation coefficient change when we change the selection of countries and when we change the period? Let's find out. We look at:

- numbers of countries (all countries worldwide and top 35)
- period:
  - 1965-2021 (maximum of available data)
  - 2000-2021 (this centruy)
  - 2011-2021 (last decade)
  - 2018 (year of defining top 35)

You can easily find the highest correlation by looking at the colors in the bottom line of each figure. The higher the correlation, the darker the colour. The darkest colour, with correlation 1.0, can be left out, that is the correlation with itself. See figure 12-16.

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Correlation between CO2 output per capita and main drivers:
Income and Technology
(for all countries worldwide, period 1965-2021,
missing (= 0) values excluded, Pearson method
```

	Income	Technology	CO2_output_per_capita
Income	1.000000	0.067184	0.592789
Technology	0.067184	1.000000	0.700326
CO2_output_per_capita	0.592789	0.700326	1.000000

Figure 12 Correlation, all countries worldwide, 1965-2021

Correlation between CO2 output per capita and main drivers:
Income and Technology
(for top 35 largest emitters of CO2 per capita in 2018,
period 1965-2021, missing (=0) values excluded, Pearson method)

	Income	Technology	CO2_output_per_capita
Income	1.000000	-0.232387	0.362833
Technology	-0.232387	1.000000	0.677572
CO2_output_per_capita	0.362833	0.677572	1.000000

Figure 13 Correlation, top 35 emitters, 1965-2021

Correlation between CO2 output per capita and main drivers:
Income and Technology
(for top 35 largest emitters of CO2 per capita in 2018,
period 2000-2021, missing (=0) values excluded, Pearson method)

	Income	Technology	CO2_output_per_capita
Income	1.000000	-0.426862	0.663161
Technology	-0.426862	1.000000	0.230886
CO2_output_per_capita	0.663161	0.230886	1.000000

Figure 14 Correlation, top 35 emitters, 2000-2021

Correlation between CO2 output per capita and main drivers:
Income and Technology
(for top 35 largest emitters of CO2 per capita in 2018,
period 2011-2021, missing (=0) values excluded, Pearson method)

	Income	Technology	CO2_output_per_capita
Income	1.000000	-0.420074	0.736225
Technology	-0.420074	1.000000	0.220634
CO2_output_per_capita	0.736225	0.220634	1.000000

Figure 15 Correlation, top 35 emitters, 2011-2021

Correlation between CO2 output per capita and main drivers:
Income and Technology
(for top 35 largest emitters of CO2 per capita in 2018,
period 2018, missing (=0) values excluded, Pearson method)

	Income	Technology	CO2_output_per_capita
Income	1.000000	-0.441007	0.668796
Technology	-0.441007	1.000000	0.272865
CO2_output_per_capita	0.668796	0.272865	1.000000

Figure 16 Correlation, top 35 emitters, 2018

Conclusion: If we look at a large group of countries (top 35 & all countries) and a large period of time (1965-2021) Technology seems to have the highest correlation with CO2 output per capita. This correlation is higher than 0.5 and therefore relevant. If we look at this century there is a shift. Income has a higher correlation (for 2000-2021, for 2011-2021, for 2018). Before we take any further conclusions we first have a look at the subdrivers that make Technology.

CO_2 output per capita and its subdrivers

Technology in the Kaya Identity is the product of Energy Intensity and Carbon Intensity. Energy intensity is about how efficient the energy is. Carbon intensity is about how clean the energy mix used is.

Technology = Energy intensity x Carbon intensity

Let's have a look at these subdrivers for the top 35 largest emitters of CO_2 output per capita in 2018. See figure 17 and 18.

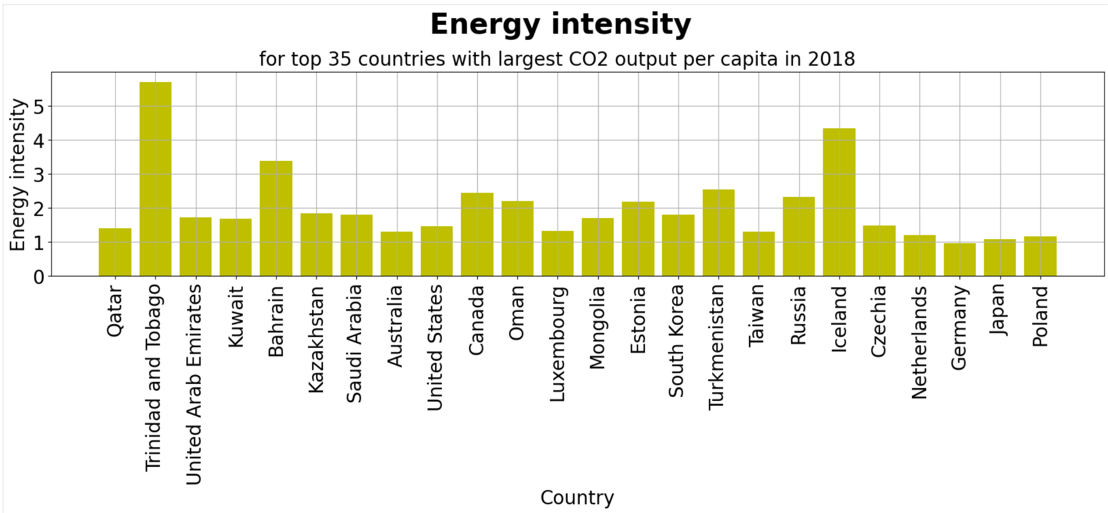

Figure 17 Energy intensity in 2018 for top 35 emitters of CO_2 per capita

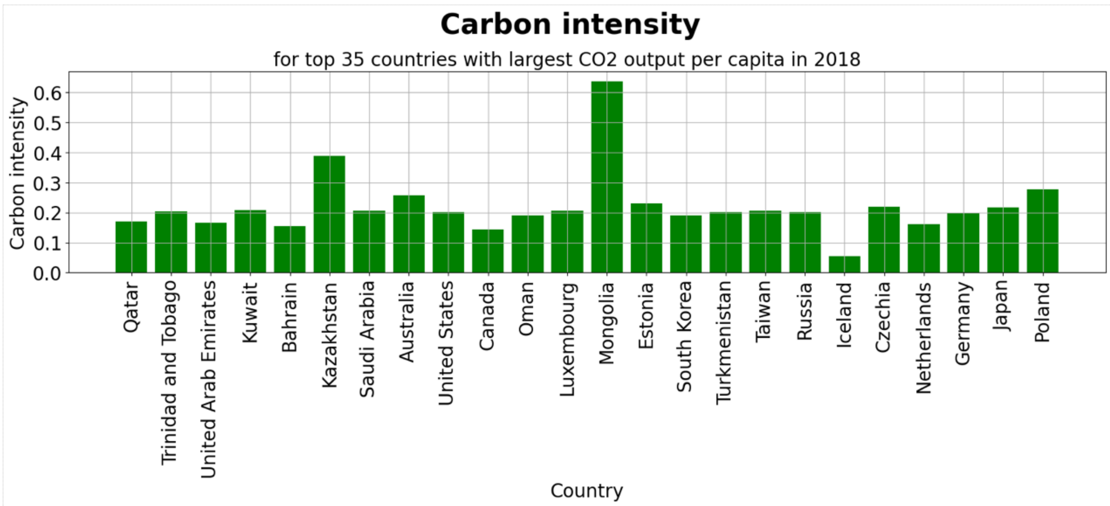

Figure 18 Carbon intensity in 2018 for top 35 emitters of CO_2 per capita

Conclusion: If we look at Energy intensity Trinidad and Tobago (no. 2. largest emitter) and Iceland (no. 29 in top 35 emitters) stand out with a high energy intensity. Meaning there is a low energy efficiency. Any number above 1 will have an enlarging effect on the CO_2 output per capita. As soon as one of the drivers is under 1, it will have a shrinking effect on the CO_2 output per capita. If we look at Carbon intensity, again Mongolia stands out with a high figure. This might explain the high figure for Technology.

Correlation between CO_2 output per capita and subdrivers

Again we can compare the relationship between CO_2 output per capita and Energy intensity and between CO_2 output per capita and Carbon intensity by applying the Pearson method for correlation. A correlation coefficient of more than 0.5 or less than -0.5 indicates a strong relationship between two elements.

The same procedure is followed. We look at:

- numbers of countries (all countries worldwide and top 35)
- period:
    - 1965-2021 (maximum of available data)
    - 2000-2021 (this century)
    - 2011-2021 (last decade)
    - 2018 (year of defining top 35)

See figure 19-23.

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Correlation between CO2 output per capita and subdrivers:
Energy intensity and Carbon intensity
(for all countries worldwide, period 1965-2021,
missing (=0) values excluded, Pearson method)
```

	Energy_intensity	Carbon_intensity	CO2_output_per_capita
Energy_intensity	1.000000	-0.054576	0.401806
Carbon_intensity	-0.054576	1.000000	0.521677
CO2_output_per_capita	0.401806	0.521677	1.000000

Figure 19 Correlation, all countries worldwide, 1965-2021

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Correlation between CO2 output per capita and subdrivers:
Energy intensity and Carbon intensity
(for top 35 largest emitters of CO2 per capita in 2018, period 1965-2021,
missing (=0) values excluded, Pearson method)
```

	Energy_intensity	Carbon_intensity	CO2_output_per_capita
Energy_intensity	1.000000	-0.054576	0.401806
Carbon_intensity	-0.054576	1.000000	0.521677
CO2_output_per_capita	0.401806	0.521677	1.000000

Figure 20 Correlation, top 35 emitters, 1965-2021

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Correlation between CO2 output per capita and subdrivers:
Energy intensity and Carbon intensity
(for top 35 largest emitters of CO2 per capita in 2018, period 2000-2021,
missing (=0) values excluded, Pearson method)
```

	Energy_intensity	Carbon_intensity	CO2_output_per_capita
Energy_intensity	1.000000	-0.282302	0.212833
Carbon_intensity	-0.282302	1.000000	-0.045031
CO2_output_per_capita	0.212833	-0.045031	1.000000

Figure 21 Correlation, top 35 emitters, 2000-2021

```
Correlation between CO2 output per capita and subdrivers:
Energy intensity and Carbon intensity
(for top 35 largest emitters of CO2 per capita in 2018, period 2011-2021,
missing (=0) values excluded, Pearson method)
```

	Energy_intensity	Carbon_intensity	CO2_output_per_capita
Energy_intensity	1.000000	-0.295955	0.274312
Carbon_intensity	-0.295955	1.000000	-0.143521
CO2_output_per_capita	0.274312	-0.143521	1.000000

Figure 22 Correlation, top 35 emitters, 2011-2021

```
Correlation between CO2 output per capita and subdrivers:
Energy intensity and Carbon intensity
for top 35 largest emitters of CO2 per capita in 2018,
period 2018, missing (=0) values excluded, Pearson method)
```

	Energy_intensity	Carbon_intensity	CO2_output_per_capita
Energy_intensity	1.000000	-0.244814	0.294462
Carbon_intensity	-0.244814	1.000000	-0.061500
CO2_output_per_capita	0.294462	-0.061500	1.000000

Figure 23 Correlation, top 35 emitters, 2018

Conclusion: If we look at a large group of countries (worldwide & top 35) and a large period of time (1965-2021) we see that Carbon intensity has a larger correlation with CO_2 output per capita than Energy intensity. If we look at the top 35 for this century (2000-2021, 2011-2021, 2018) we see a shift. Energy intensity gets a larger correlation with CO_2 output per capita than Carbon intensity. The correlation coefficients for Carbon intensity even get negative.

Zoom in at world's top 3 emitters of CO_2 per capita

Let's zoom in at the top three emitters of CO_2 per capita in 2018 (where data is complete for all the drivers that we want to look into):

#1 Qatar
#2 Trinidad & Tobago
#3 United Arab Emirates

1. Absolute changes in CO_2 output per capita and drivers

For these three countries with the largest CO_2 output per capita in the world we look closer at how Income and Technology impact the CO_2 emissions from 1965 until 2018 / 2021. See figure 11 with the absolute values. Each country represent a color and a bar so we can what happens.

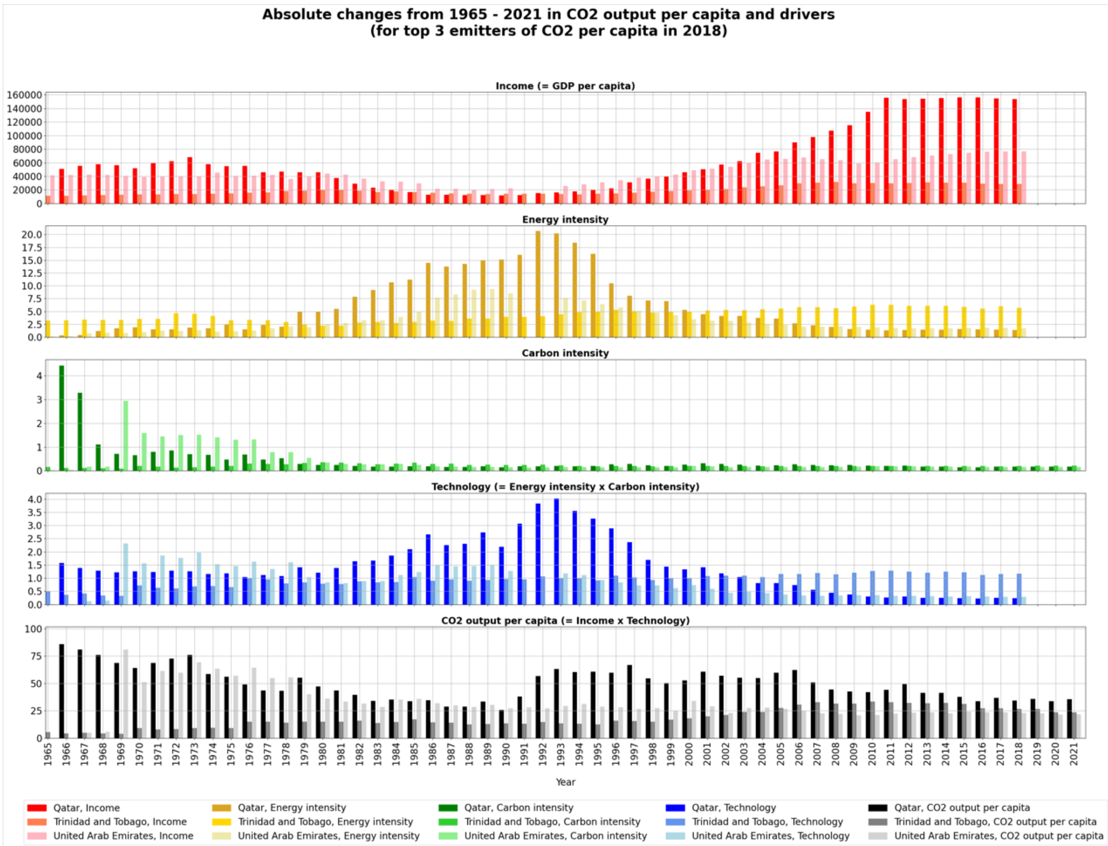

Figure 24 CO_2 output per capita and key elements Kaya Identity 1965-2021

Figure 24 confirms the impact of a growing Income (top plot) on the CO_2 output per capita. The three top CO_2 emitters all have a growing Income (GDP per capita) in the last decades. The shrinking Energy intensity and shrinking Carbon intensity cannot compensate for this Income growth.

If we zoom in on this century we see that Qatar has the biggest Income growth. Trinidad and Tobago have a high and stable Energy intensity. Qatar's carbon intensity is reduced more than those of Trinidad and Tobago and the United Arab Emirates. Furthermore, Qatar shows the largest reduction in CO_2 emissions per capita. See figure 25.

Finally we zoom in at the last decade. There we see that for 2019, 2020 and 2021 not all data is complete. See figure 26.

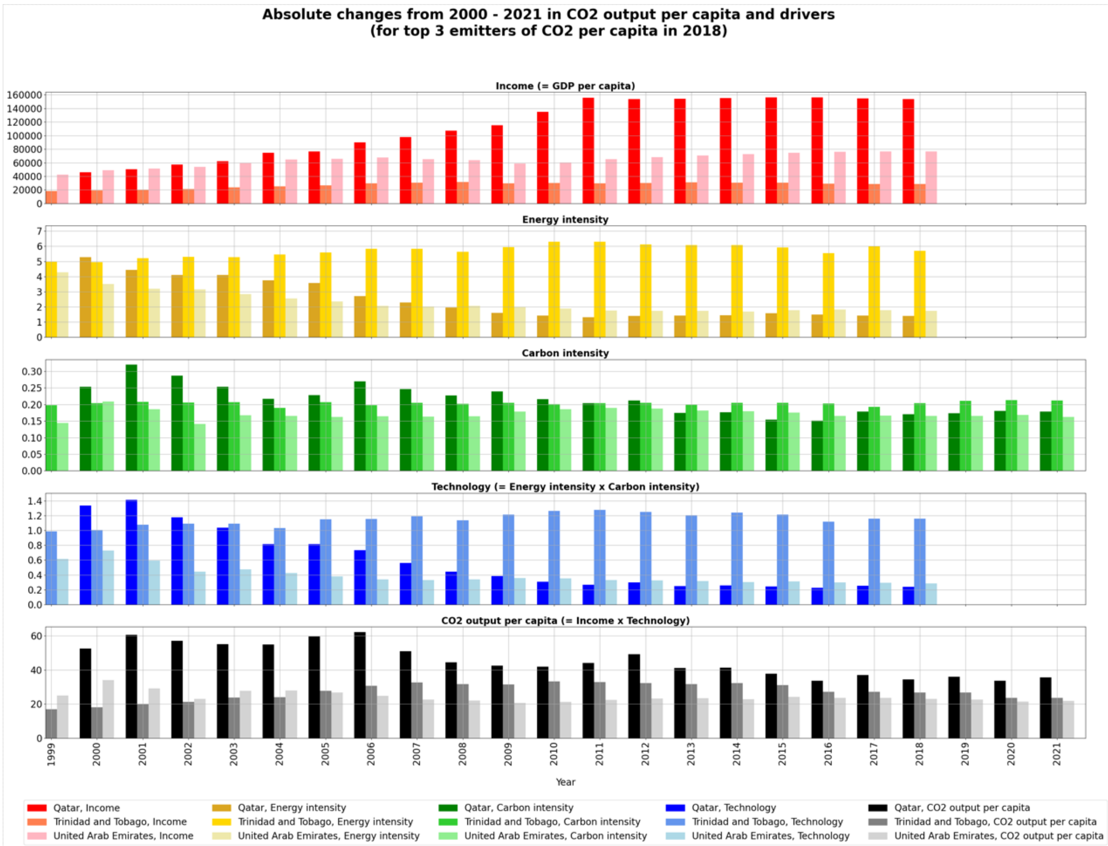

Figure 25 CO_2 output per capita and key elements Kaya Identity 2000-2021

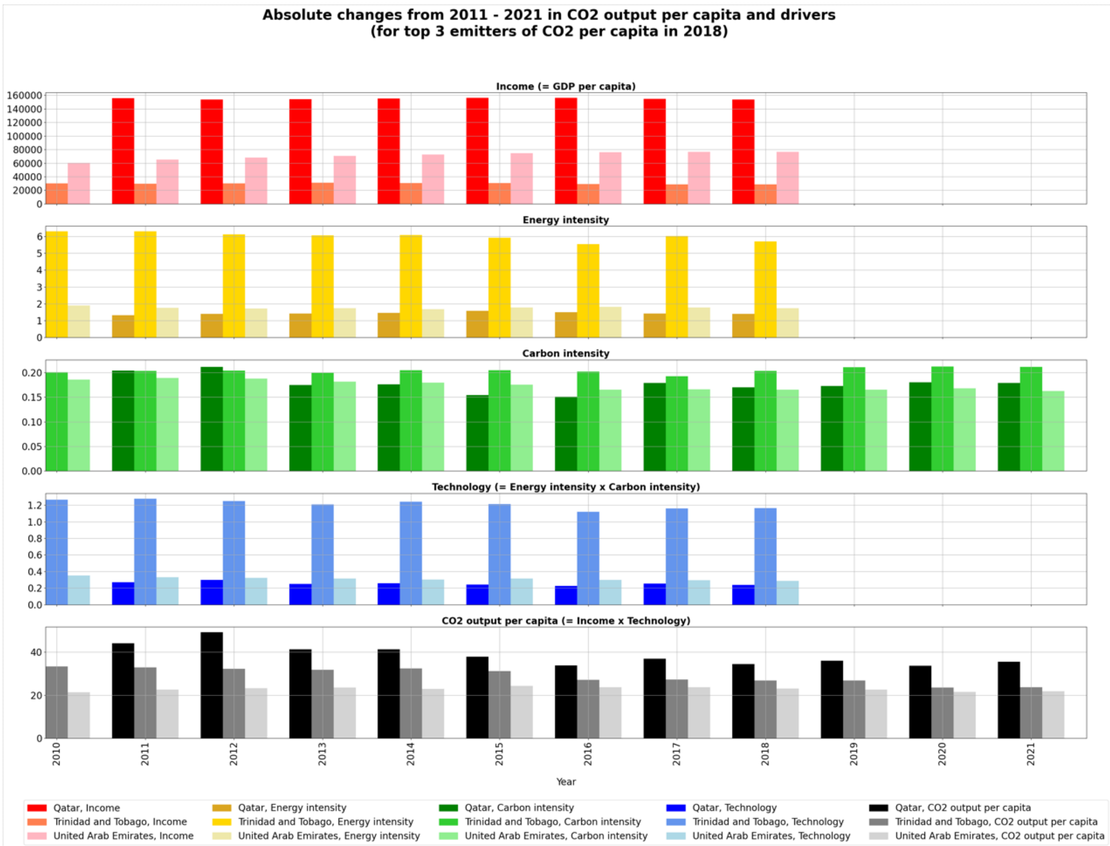

Figure 26 CO_2 output per capita and key elements Kaya Identity 2011-2021

To clarify this further we will look at the relative changes in the key drivers of CO_2 output per capita (Income and Technology (Energy intensity and Carbon intensity).

2. Relative changes in CO_2 output per capita and drivers

Interesting in figure 27 is to see that the largest relative change is the CO_2 output per capita by United Arab Emirates, which is far more significant than then the rest. Data shows that since 2019 the United Arab Emirates are no longer in the top 5 CO_2 output per capita. Because the data of all the drivers is not complete for the years after 2018, this could be further investigated in case more data will be available in the future.

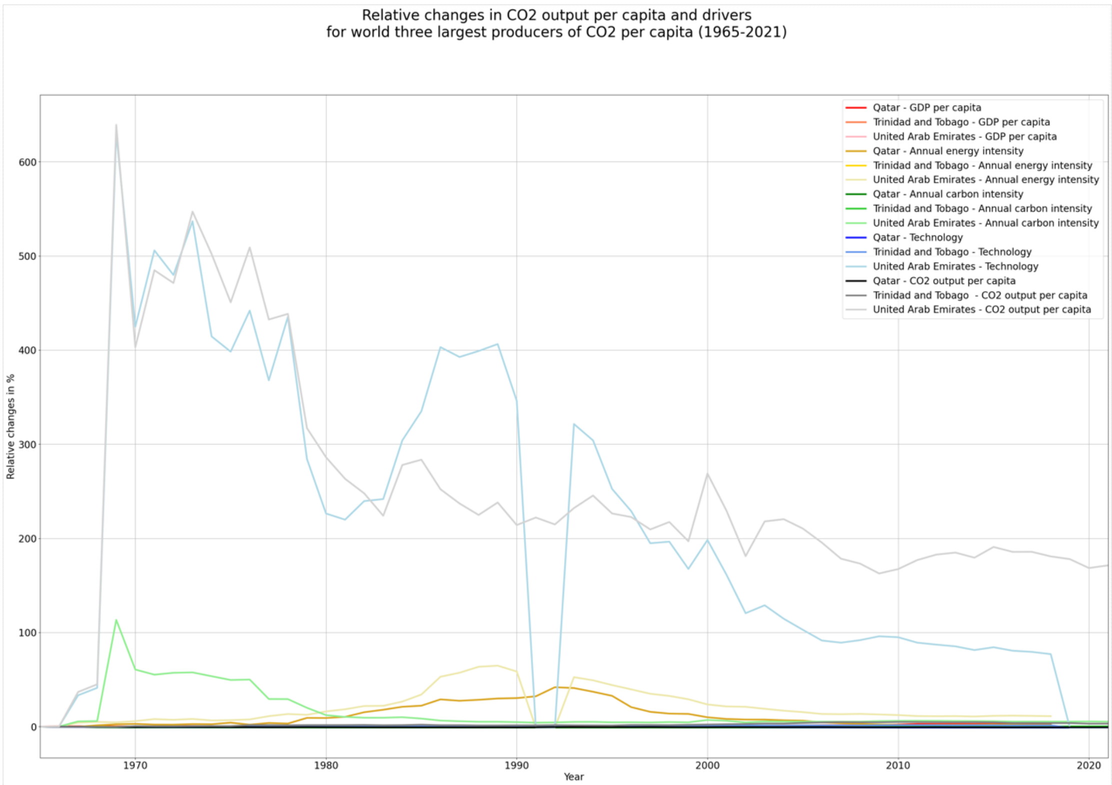

Figure 27 Relative changes in % CO_2 output per capita and drivers for top 3

3. Correlation coefficients for CO_2 output per capita and drivers

Again we can compare the relationship between CO_2 output per capita and its drivers by applying the Pearson method for correlation. A correlation coefficient of more than 0.5 or less than -0.5 indicates a strong relationship between two elements.

The same procedure is followed. We look at:

- top 3 emitters of CO_2 per capita in 2018
- period:
  - 1965-2021 (maximum of available data)
  - 2000-2021 (this century)

- 2011-2021 (last decade)
- 2018 (year of defining top 35)

See figure 28-31.

Correlation between CO2 output per capita and drivers
(for top 3 emitters CO2 per capita in 2018, period 1965-2021,
missing (=0) values excluded, Pearson method)

	Energy_intensity	Income	Carbon_intensity	Technology	CO2_output_per_capita
Energy_intensity	1.000000	-0.438857	-0.279357	0.775191	0.029832
Income	-0.438857	1.000000	0.022348	-0.435302	0.311656
Carbon_intensity	-0.279357	0.022348	1.000000	0.254169	0.614768
Technology	0.775191	-0.435302	0.254169	1.000000	0.506051
CO2_output_per_capita	0.029832	0.311656	0.614768	0.506051	1.000000

Figure 28 Correlation, top 3 emitters, 1965-2021

Correlation between CO2 output per capita and drivers
(for top 3 emitters CO2 per capita in 2018, period 2000-2021,
missing (=0) values excluded, Pearson method)

	Energy_intensity	Income	Carbon_intensity	Technology	CO2_output_per_capita
Energy_intensity	1.000000	-0.802101	0.335649	0.964670	-0.044577
Income	-0.802101	1.000000	-0.172406	-0.748391	0.374344
Carbon_intensity	0.335649	-0.172406	1.000000	0.558391	0.731508
Technology	0.964670	-0.748391	0.558391	1.000000	0.157609
CO2_output_per_capita	-0.044577	0.374344	0.731508	0.157609	1.000000

Figure 29 Correlation, top 3 emitters, 2000-2021

Correlation between CO2 output per capita and drivers
(for top 3 emitters CO2 per capita in 2018, period 2011-2018(2021),
missing (=0) values excluded, Pearson method)

	Energy_intensity	Income	Carbon_intensity	Technology	CO2_output_per_capita
Energy_intensity	1.000000	-0.797411	0.657017	0.998397	-0.135603
Income	-0.797411	1.000000	-0.509338	-0.791428	0.650859
Carbon_intensity	0.657017	-0.509338	1.000000	0.694661	0.189051
Technology	0.998397	-0.791428	0.694661	1.000000	-0.111259
CO2_output_per_capita	-0.135603	0.650859	0.189051	-0.111259	1.000000

Figure 30 Correlation, top 3 emitters, 2011-2021

Correlation between CO2 output per capita and drivers
(for top 3 emitters CO2 per capita in 2018, period 2018,
missing (=0) values excluded, Pearson method)

	Energy_intensity	Income	Carbon_intensity	Technology	CO2_output_per_capita
Energy_intensity	1.000000	-0.831125	0.983794	0.999742	-0.256919
Income	-0.831125	1.000000	-0.717946	-0.818273	0.750952
Carbon_intensity	0.983794	-0.717946	1.000000	0.987614	-0.079469
Technology	0.999742	-0.818273	0.987614	1.000000	-0.234889
CO2_output_per_capita	-0.256919	0.750952	-0.079469	-0.234889	1.000000

Figure 31 Correlation, top 3 emitters, 2018

Conclusion: For the top 3 emitters we see a similar pattern than for the larger group. If we regard a large period (1965-2021) Carbon intensity (and Technology) have the largest correlation with the CO2 output per capita. If we look at this century it shifts to Income (GDP per capita). If we look at 2018, Income has a large correlation with CO2 output per capita (0.75) and the other drivers show a much smaller and negative correlation.

Let's zoom in at the top emitter of CO_2 per capita: Qatar.

Zoom in at world's top emitter of CO_2 per capita: Qatar

For the top emitter of CO2 per capita in 2018 we look closer at the absolute values for CO2 output per capita and its drivers (figure 32), the relative changes in the CO2 output per capita (figure 33) and its drivers and the correlation coefficients as we did before (figure 34-36).

1. Absolute changes in CO_2 output per capita and drivers

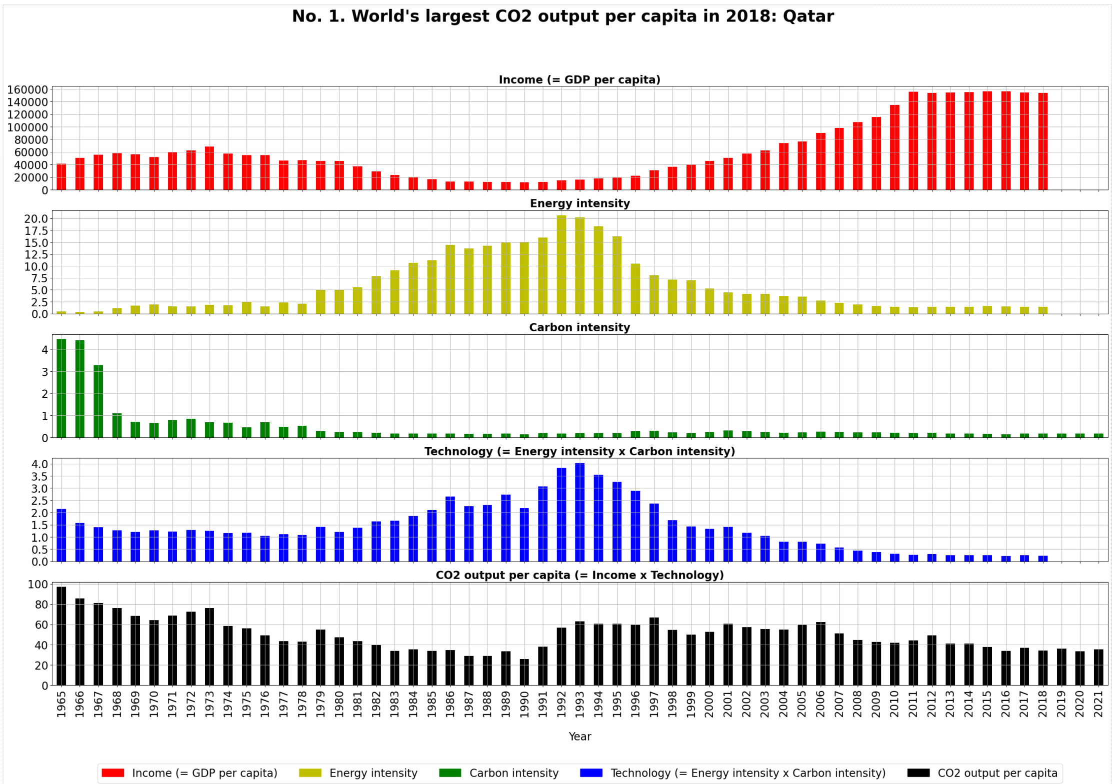

Figure 32 Qatar: CO_2 output capita and drivers (absolute values)

2. Relative changes in CO_2 output per capita and drivers

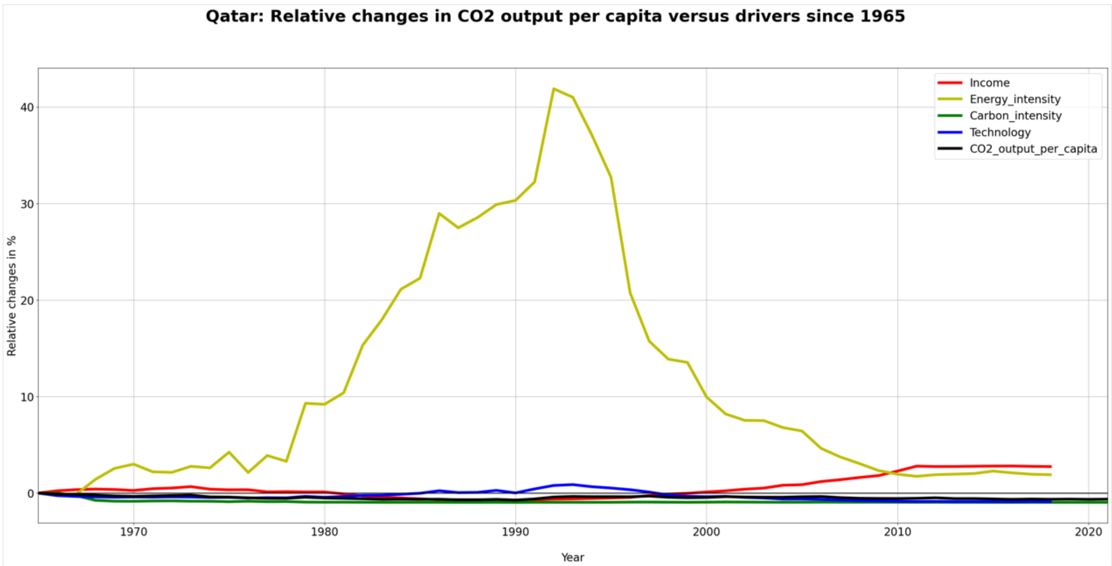

Figure 33 Qatar: CO_2 output capita and drivers (relative changes since 1965)

3. Correlation coefficients for CO_2 output per capita and drivers

The relationship between CO_2 output per capita and its drivers is compared by applying the Pearson method for correlation. A correlation coefficient of more than 0.5 or less than -0.5 indicates a strong relationship between two elements.

The same procedure is followed. We look at:
- nr. 1 emitters of CO_2 per capita in 2018, Qatar
- period[7]:
  - 1965-2021 (maximum of available data)
  - 2000-2021 (this century)
  - 2011-2021 (last decade)

See figure 34-36.

Qatar: Correlation between CO2 output per capita and drivers
period 1965-2021, missing (=0) values excluded, Pearson method)

	Energy_intensity	Income	Carbon_intensity	Technology	CO2_output_per_capita
Energy_intensity	1.000000	-0.669482	-0.319287	0.886070	-0.294893
Income	-0.669482	1.000000	-0.094212	-0.827316	-0.132462
Carbon_intensity	-0.319287	-0.094212	1.000000	0.038299	0.686337
Technology	0.886070	-0.827316	0.038299	1.000000	0.121867
CO2_output_per_capita	-0.294893	-0.132462	0.686337	0.121867	1.000000

Figure 34 Correlation, Qatar, 1965-2021

[7] 2018 (year of defining top 35) is left out, because with 1 value per driver, the correlation cannot be defined.

Qatar: Correlation between CO2 output per capita and drivers
period 2000-2021, missing (=0) values excluded, Pearson method)

	Energy_intensity	Income	Carbon_intensity	Technology	CO2_output_per_capita
Energy_intensity	1.000000	-0.950559	0.733925	0.976392	0.780844
Income	-0.950559	1.000000	-0.857961	-0.956964	-0.846882
Carbon_intensity	0.733925	-0.857961	1.000000	0.843235	0.855348
Technology	0.976392	-0.956964	0.843235	1.000000	0.816339
CO2_output_per_capita	0.780844	-0.846882	0.855348	0.816339	1.000000

Figure 35 Correlation, Qatar, 2000-2021

Qatar: Correlation between CO2 output per capita and drivers
period 2011-2018(2021), missing (=0) values excluded, Pearson method)

	Energy_intensity	Income	Carbon_intensity	Technology	CO2_output_per_capita
Energy_intensity	1.000000	0.495880	-0.779281	-0.490041	-0.437666
Income	0.495880	1.000000	-0.485907	-0.423521	-0.320229
Carbon_intensity	-0.779281	-0.485907	1.000000	0.926750	0.869187
Technology	-0.490041	-0.423521	0.926750	1.000000	0.946120
CO2_output_per_capita	-0.437666	-0.320229	0.869187	0.946120	1.000000

Figure 36 Correlation Qatar, 2011-2018 (not enough values for 2019-2021)

Conclusion: The top emitter of CO_2 per capita in 2018, Qatar, Carbon intensity has the largest correlation with the CO_2 output per capita has we we look at a larger period of time (1965-2021). If we look at the figures fot this century (2000-2021) Carbon intensity, energy intensity and techology seem to have a large correlation with the CO2 output per capita. Whereas technology is of course the product of Carbon intensity and Energy intensity. If we zoom in at this decade (2011-2018(2021) we see that Technology and Carbon intensity have a very large correlation with the CO2 output per capita.

Let's see if a visualisation in graphs confirms the conclusion. The graphs show the correlation between Carbon intensity and CO_2 output per capita for Qatar for:

- 1965-2018
- 1969-2018
- 2000-2018
- 2011-2018

Let's explain the chosen timeframes. Figures after 2018 are not complete for all drivers of CO_2 output per capita and therefore left out. In the first graph you that the values for 1965, 1966 and 1967 how a much larger carbon intensity than the other years. The other years are not readable in the graph. In the next graph these years are left. Something similar happens. The values for the years 1969 - 1978 describe more than half of the graph. More recent years are unreadable because there are the values in Carbon intensity are relatively close. If we zoom in on this century the correlation becomes more and more consistent. The more recent the year, the lower the carbon intensity and the lower the CO_2 output per capita. See figure 37-40.

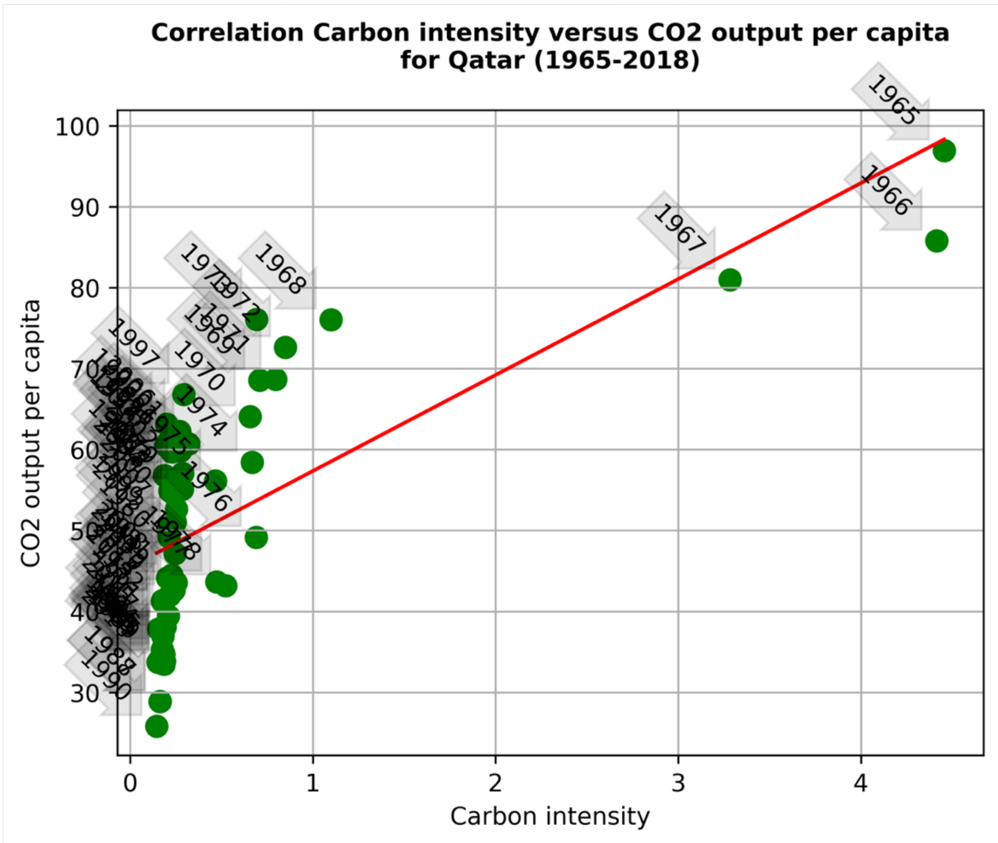

Figure 37 Correlation Qatar, 1965-2018

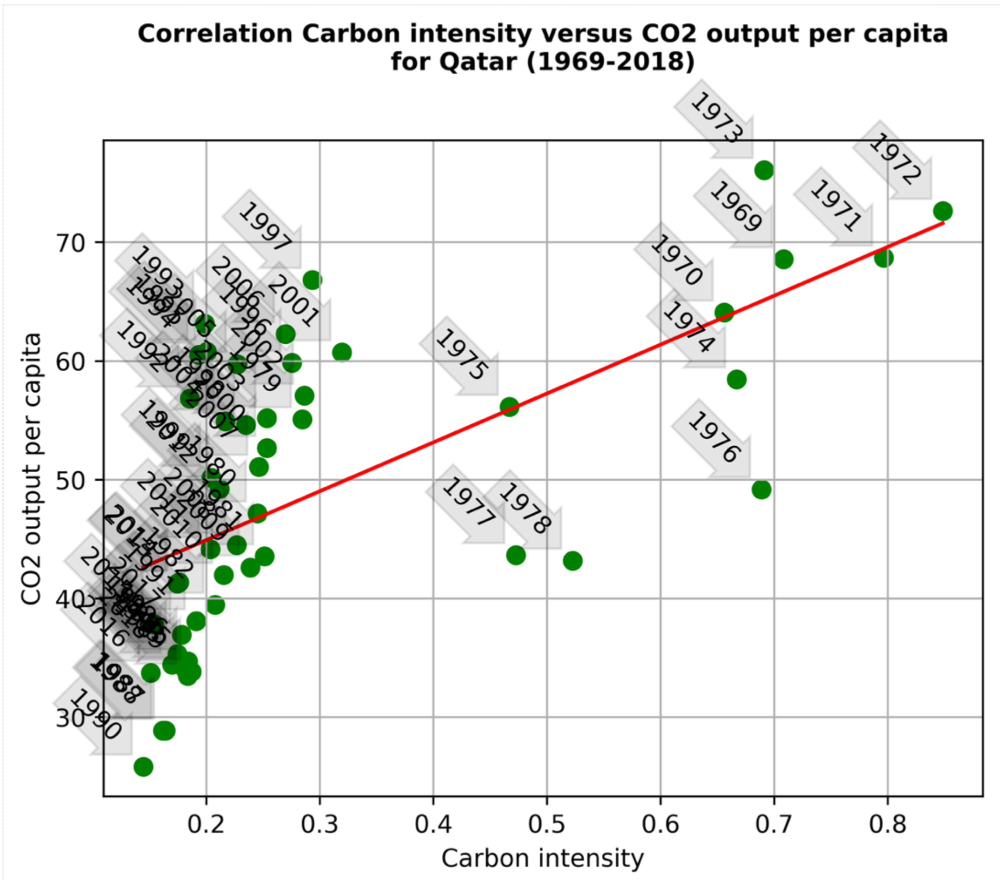

Figure 38 Correlation, Qatar, 1969-2018

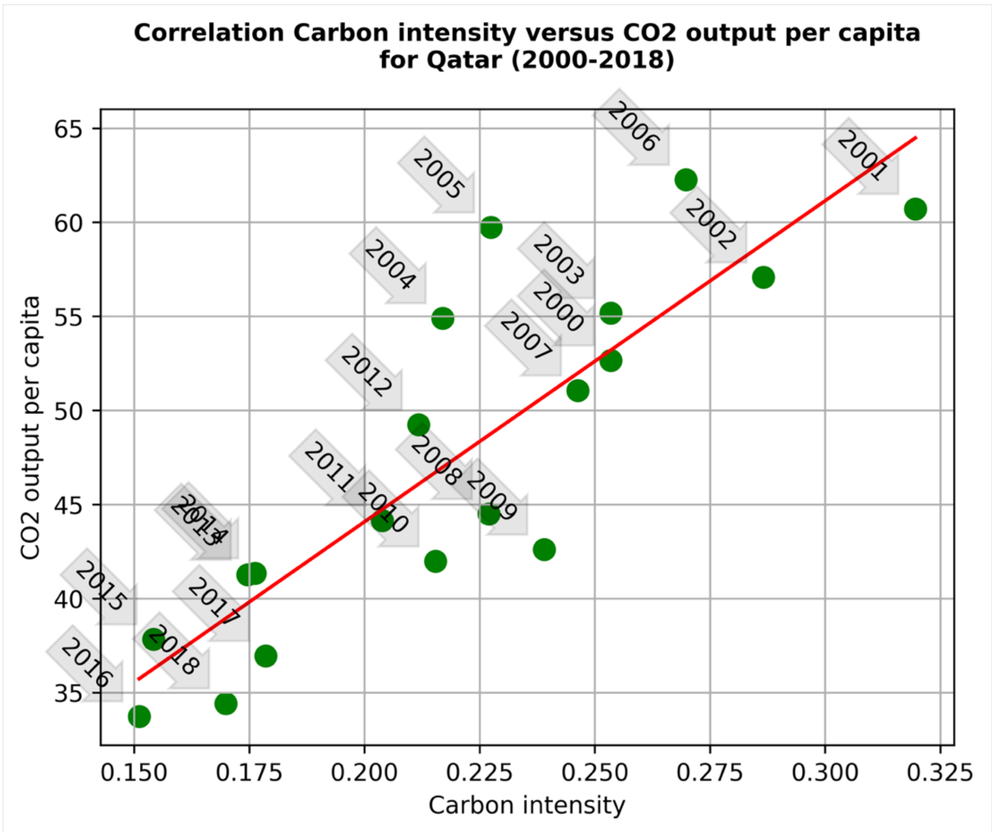

Figure 39 Correlation, Qatar, 2000-2018

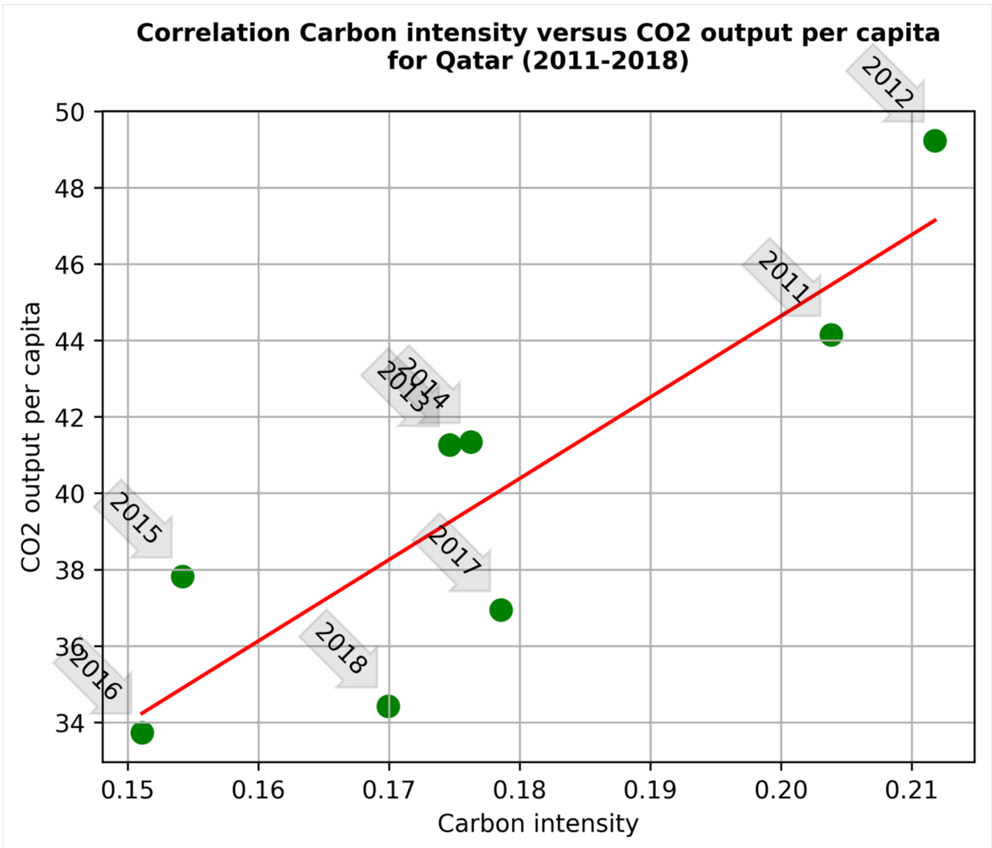

Figure 40 Correlation, Qatar, 2011-2018

CONCLUSION

The goal of this analysis was to find the biggest predictor of a large CO_2 output per capita per country. The Kaya Identity model was rebuilt to the following definition of CO_2 output per capita:

CO_2 output per capita = Income x Technology

Technology = Energy intensity x Carbon intensity

Where Energy intensity is about: how efficient is energy produced?
And Carbon intensity is about: how clean is the energy mix?

For 2018, the last year where data was fully available for CO_2 output and its drivers, the top 35 countries with the largest CO_2 output per capita were researched: CO_2 output per capita, Income, Technology, Energy intensity and Carbon intensity. This was done for the following periods:

- 1965-2021
- 2000-2021
- 2011-2021
- 2018 (the year where the top 35 was defined)

For: absolute changes in values, relative changes since 1965 and correlation between CO_2 output per capita and its drivers.

This research was repeated for the top 3 emitters (Qatar, Trinidad and Tobago, United Arab Emirates). And finally the research zoomed in at the top CO_2 emitter Qatar.

The results of the correlation coefficients according to the Pearson method show three conclusions:

- *over a large number of countries and a large period (1965-2021) Carbon intensity seems to have the largest correlation with the CO_2 output per capita.*
- *there seems to be a shift in this century towards Income, having a larger influence on the CO_2 output per capita.*
- *if we zoom in at the top emitter of CO_2 per capita Carbon intensity and Technology have a clear relationship. Over time Carbon intensity becomes smaller and CO_2 output per capita seems to shrink with this downward trend.*

Further analysis could be of interest to find out why a growing Income (GDP per capita) seems to become a more and more important predictor of a large CO_2 output per capita. For now I would conclude that **Carbon intensity is the largest predictor of a large CO_2 output per capita**.

Note: In the end if carbon intensity is zero, which is a way to go, but not impossible... that would mean that the CO_2 output per capita would be zero. Mathematically seen: for a product or service, if one part is zero, the outcome will be zero.

DATA ANALYSIS 2.

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

This chapter will reveal which countries are making the biggest positive impact in decreasing CO_2 output. Therefore the relative CO_2 output for each country is analyzed. Growing and shrinking populations are taken into account by looking at the CO_2 output per capita. Just like in the previous analysis.

The first graph (41) shows the top 35 countries with the biggest reduction in CO_2 output per capita for the values of 1965 and 2021 compared. Sint Maarten (Dutch part) takes the lead, followed by Qatar, Curacao, Kuwait and Luxembourg. The other countries follow with relative small reductions in CO_2 per capita.

After that there is a series of three graphs (42, 43, and 44) that show the difference in the top 5 biggest reducers of CO_2 per capita for the following periods:

- 1965-2021
- 2000-2021
- 2011-2021

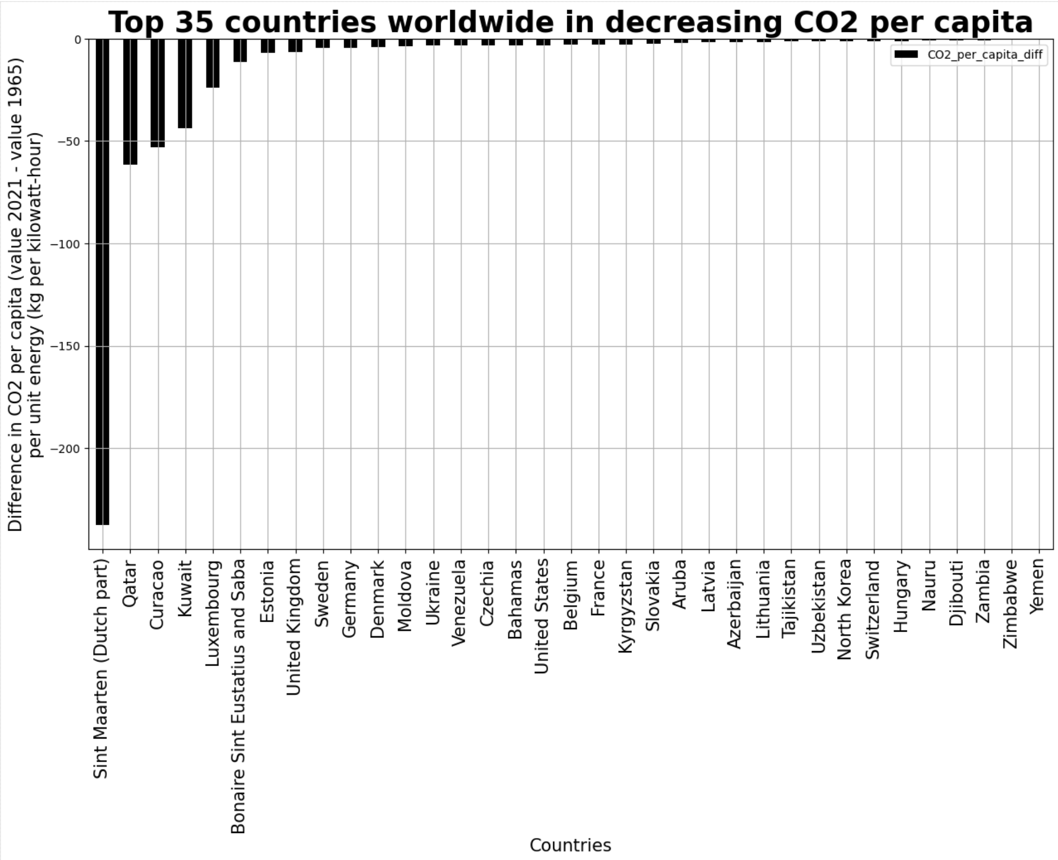

Figure 41 Top 35 reducers of CO_2 output per capita, 1965-2021

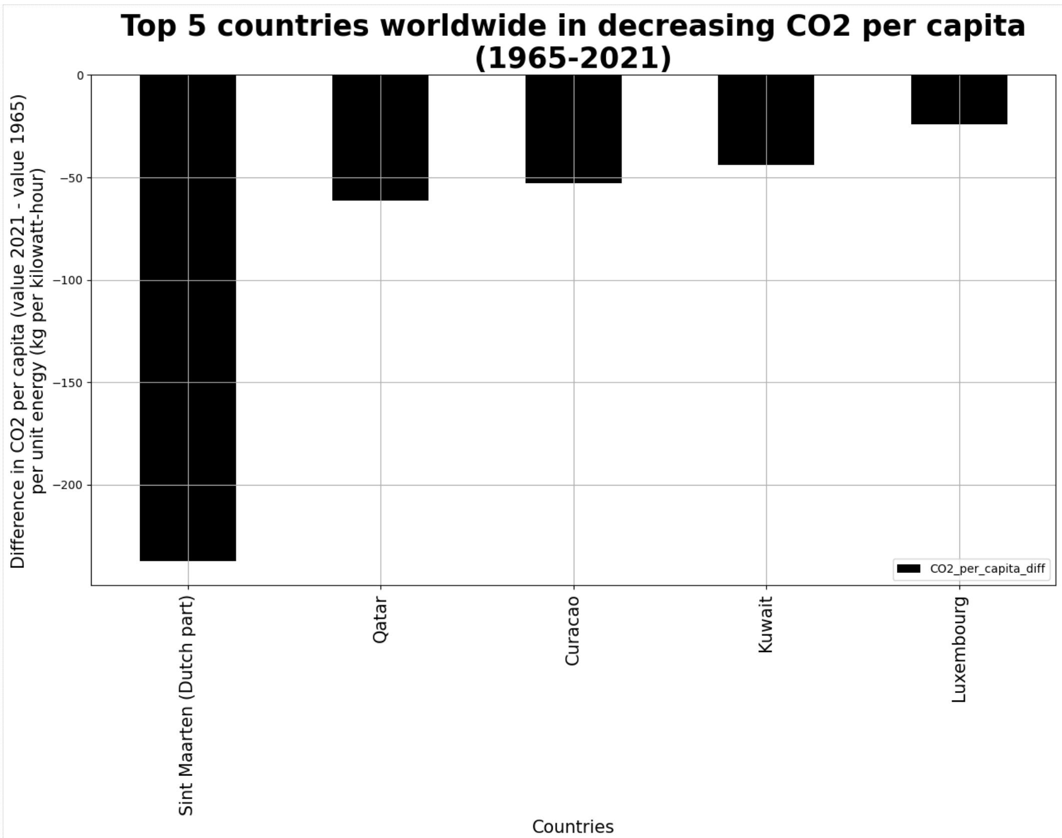

Figure 42 Top 5 reducers of CO_2 output per capita, 1965-2021

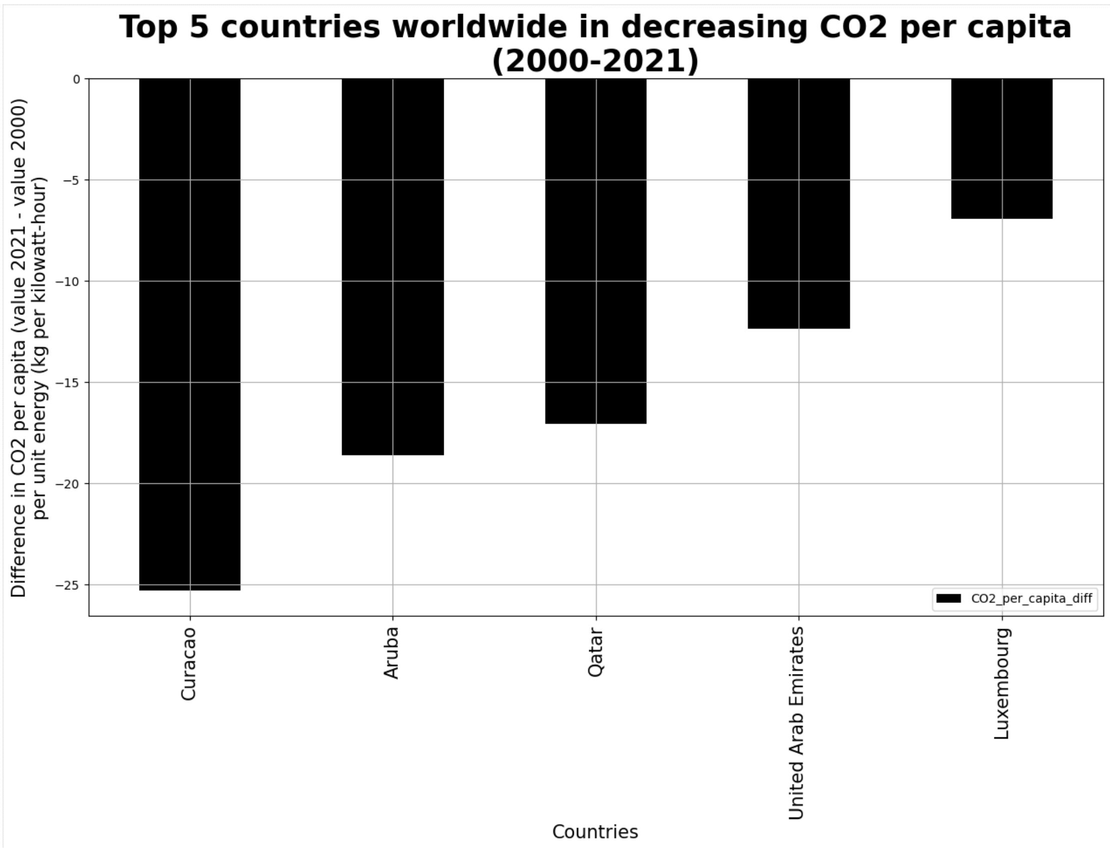

Figure 43 Top 5 reducers of CO_2 output per capita, 2000-2021

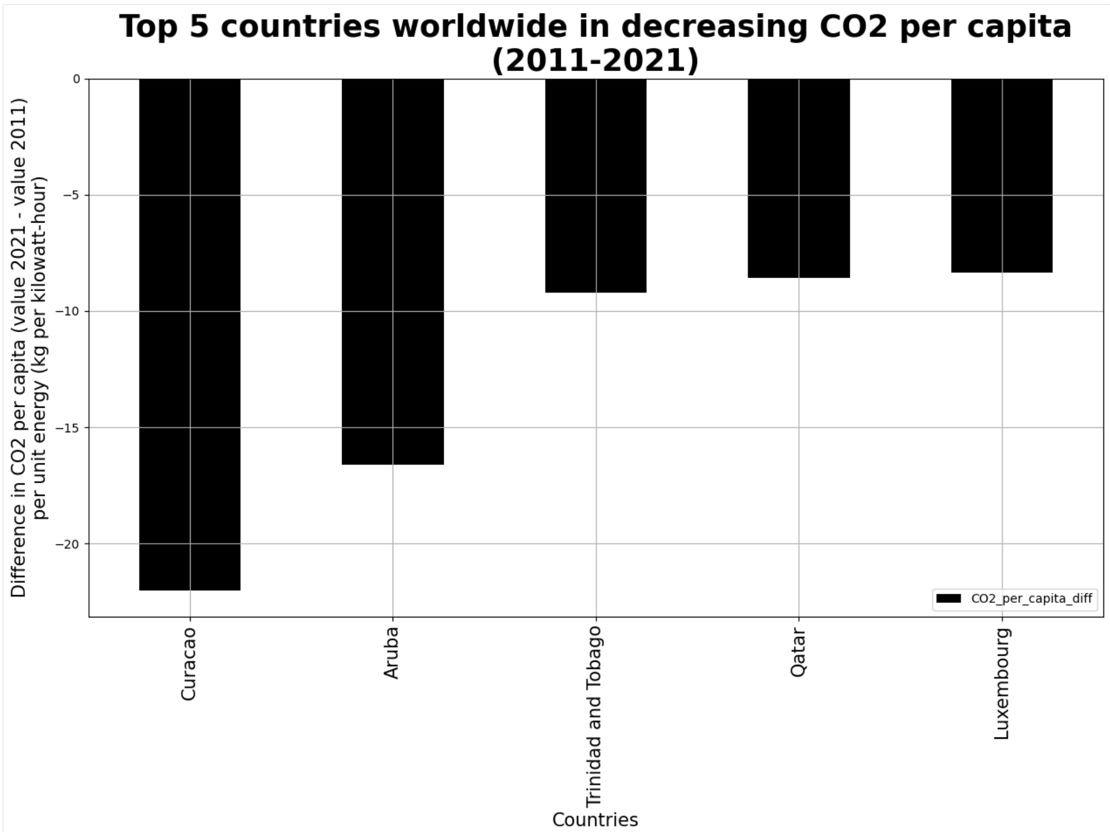

Figure 44 Top 5 reducers of CO_2 output per capita, 2011-2021

If we zoom in at the details (figure 45) we see that Kuwait has an outlier in 1991. This could be further investigated.

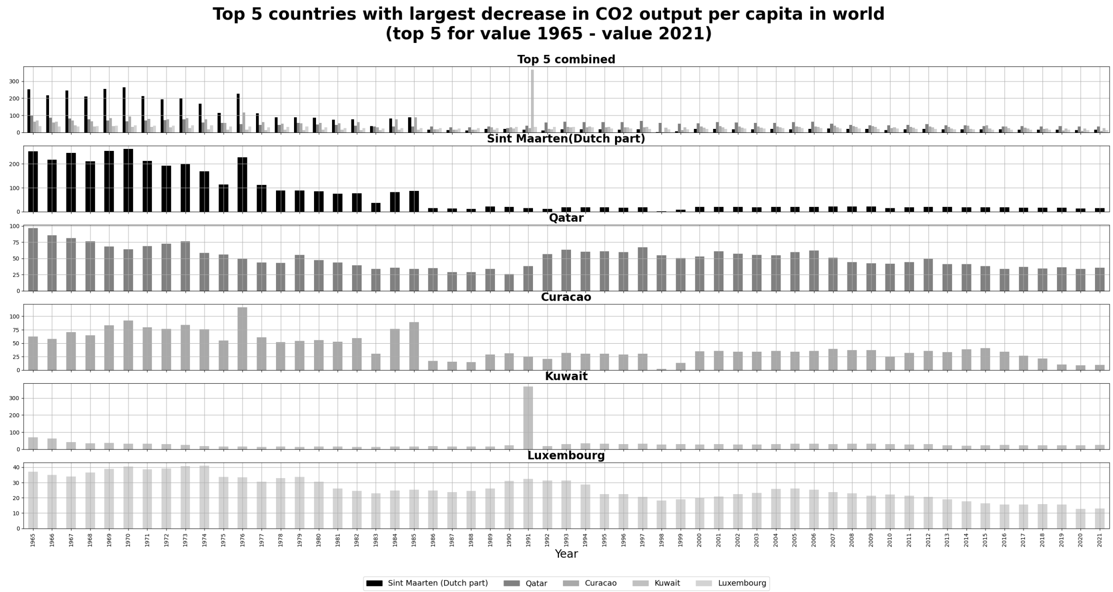

Figure 45 Combined graph + separate graphs for top 5 decreasers of CO2/capita

Conclusion: **Seen over a long period of time (1965-2021) Sint Maarten (Ductch part) is the biggest reducer of CO_2 output per capita**. **If we look at this decade Curacao makes the biggest strides in reducing CO_2 output per capita.** Followed by Aruba. Qatar who is the top emitter of CO_2 output per capita (see previous chapter) is also in the top 5 of all analyses above (1965-2021, 2000-2021, 2011-2021).

DATA ANALYSIS 3.

Which nonfossil fuel energy technology will have the best price in the future?

This last subanalysis aims to find out what nonfossil fuel energy technology will have the best price in the future.

According to Our World in Data fossil fuels dominate the global power supply because until very recently electricity from fossil fuels was the cheapest. This has changed dramatically, says Max Roser in his article 'Why did reneweables become so cheap so fast?' on December 1st, 2020 on Our World in Data[8]. Renewable energy technologies follow learning curves says Roser. The price of electricity from fossil fuel sources doesn't follow learning curves and is quite stable. If we want to transition to renewables it is their price relative to fossil fuels that matters.

According to Roser electricity from coal was historically cheap and still is, but it is not getting cheaper. This is for two reasons:

- *There is little room for improving the efficiency of coal power plants substantially*
- *The price of electricity from all fossil fuels is not only determined by the technology but to a significant extent by the cost of the fuel*

[8] https://ourworldindata.org/cheap-renewables-growth

itself. This means there is a floor below which the price of electricity cannot pass.

The costs of fossil fuels and nuclear power depend largely on the price of the fuel that they burn and the power plant's operating costs. For renewable energy this is different. Only the cost of the power plant, the cost of the technology itself is determining the cost of renewable power.

The analysis is focused on the assumption that nonfossil fuel energy technology needs to be cheaper than electricity from fossil fuels.

The nonfossil fuel energy technologies analyzed are:

- Bioenergy
- Geothermal energy
- Offshore wind energy
- Solar photovoltaic energy
- Concentrated solar power energy
- Hydropower energy
- Onshore wind energy

The source is the levelized cost of energy by technology.[9] It is the average cost per unit of energy generated across the lifetime of a new power plant. Data is expressed in US dollars per kilowatt-hour, adjusted for inflation. In the graphs the low end of the price range for fossil fuels in introduced by a line (0.05 $/kWh, source = note 9).

First an overview of the prices for nonfossil energy (figure 46):

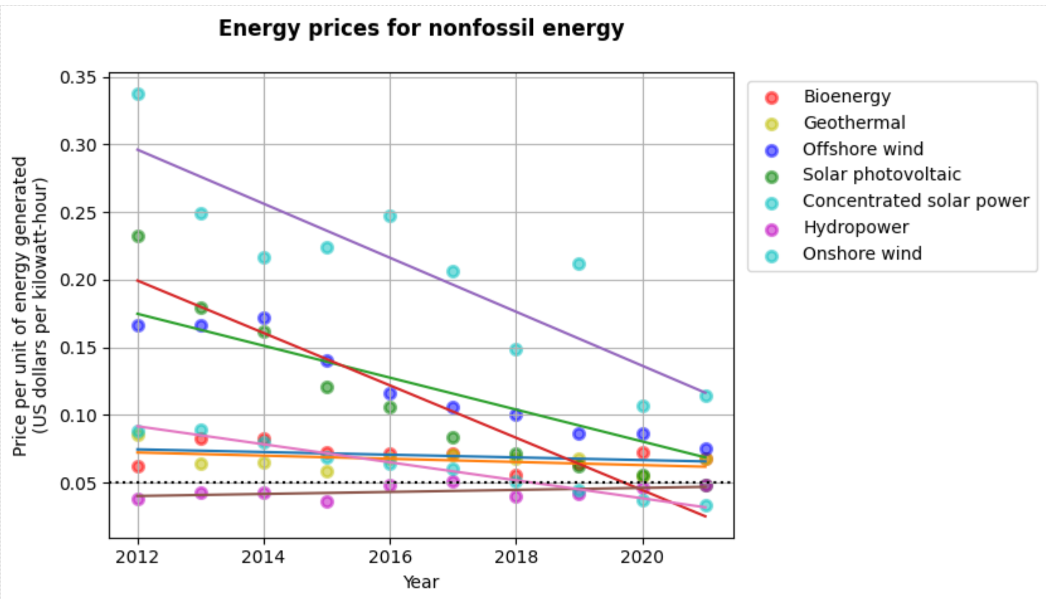

Figure 46 Energy prices for several nonfossil fuel energy technologies

Then the prices per nonfossil fuel energy technology with the extended linear regression line as a prediction im figures 47-53.

[9] https://ourworldindata.org/grapher/levelized-cost-of-energy?facet=none

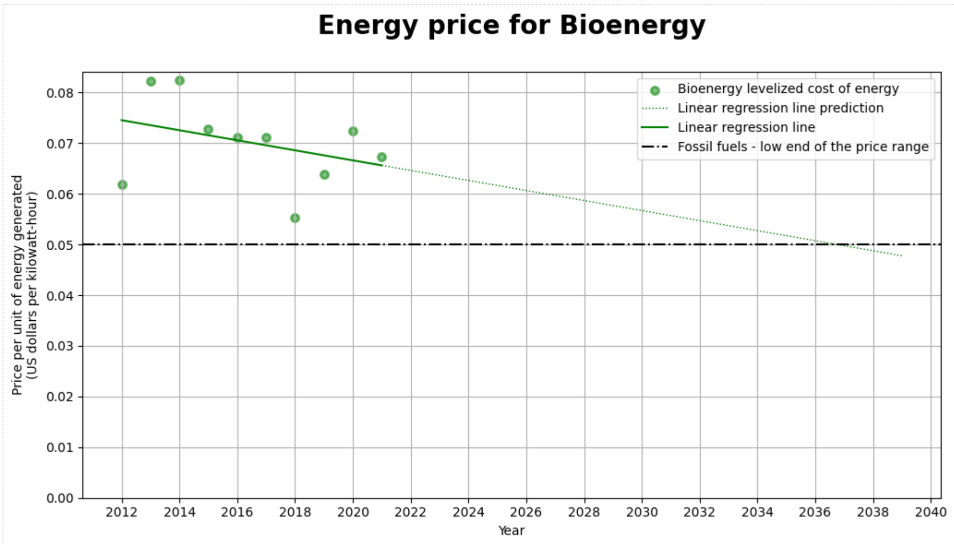

Figure 47 Energy price for bioenergy

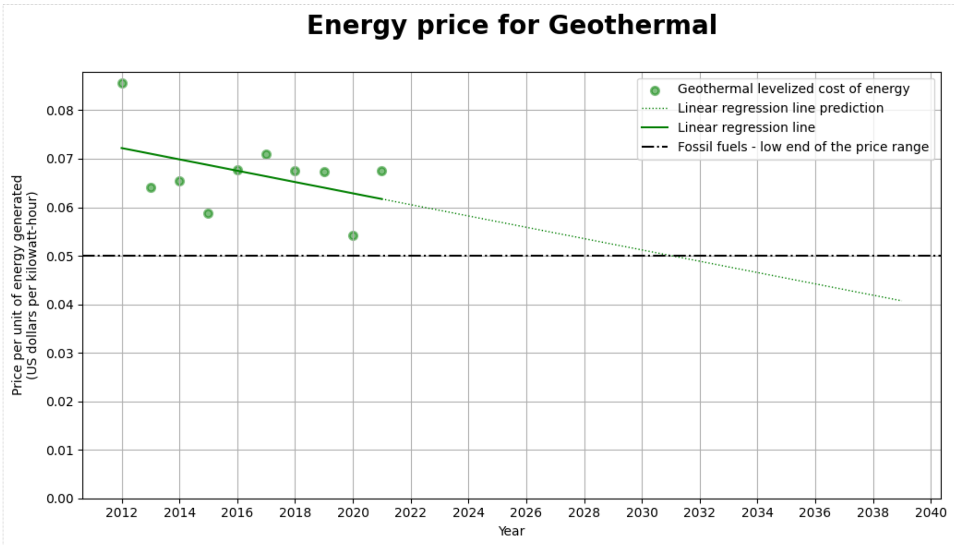

Figure 48 Energy price for geothermal energy

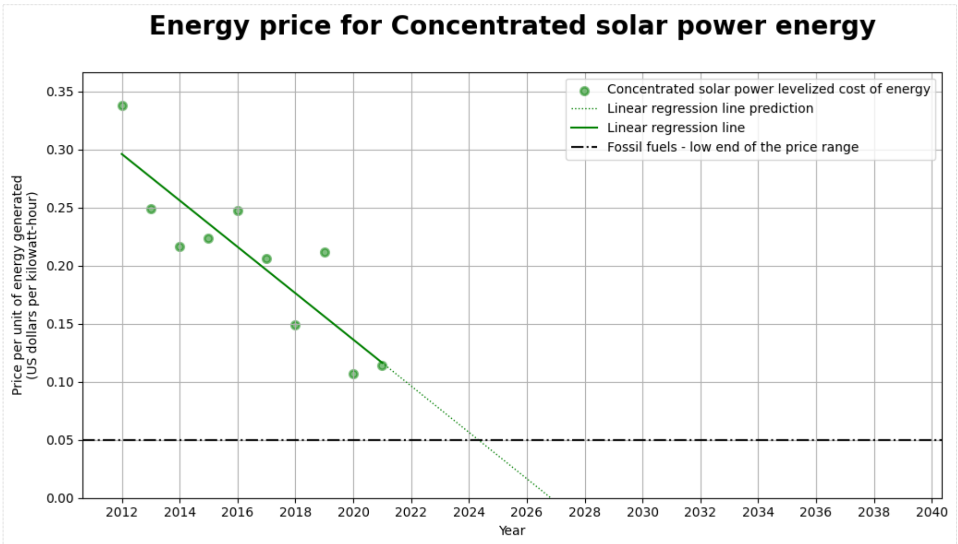

Figure 49 Energy price for concentrated solar power energy

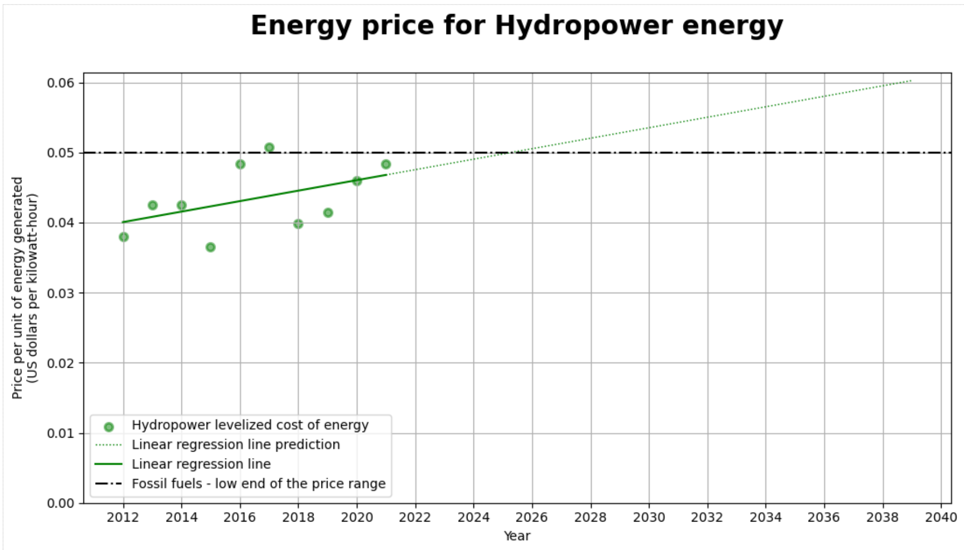

Figure 50 Energy price for hydropower energy

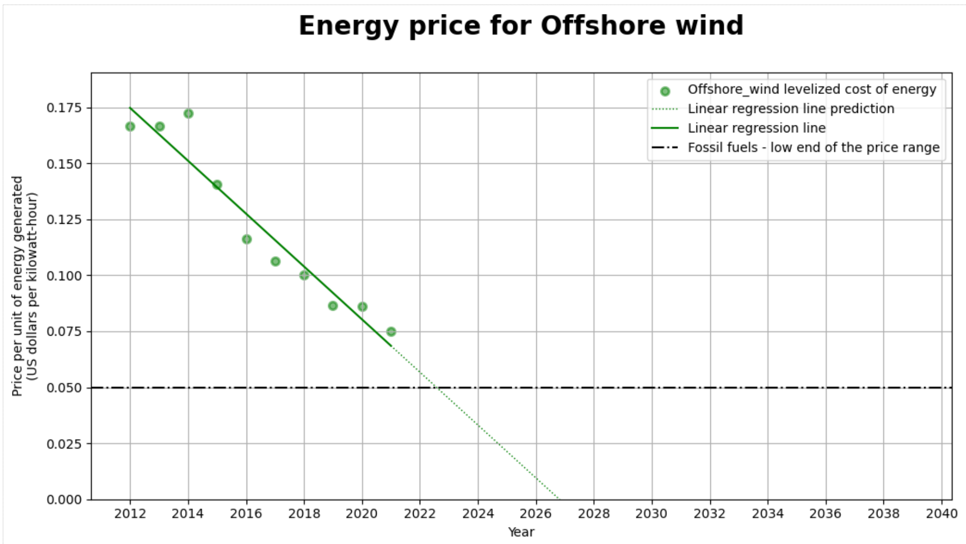

Figure 51 Energy price for offshore wind technology

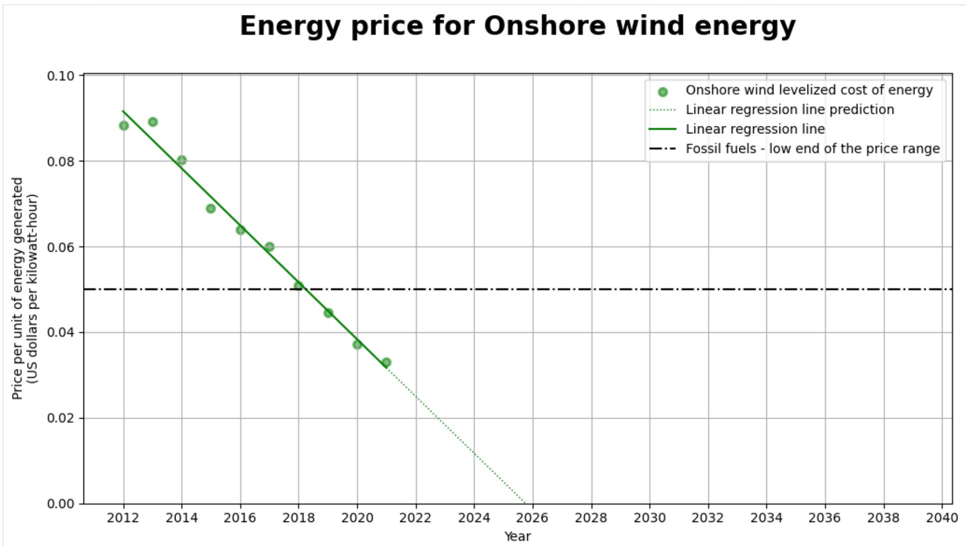

Figure 52 Energy price for Onshore wind technology

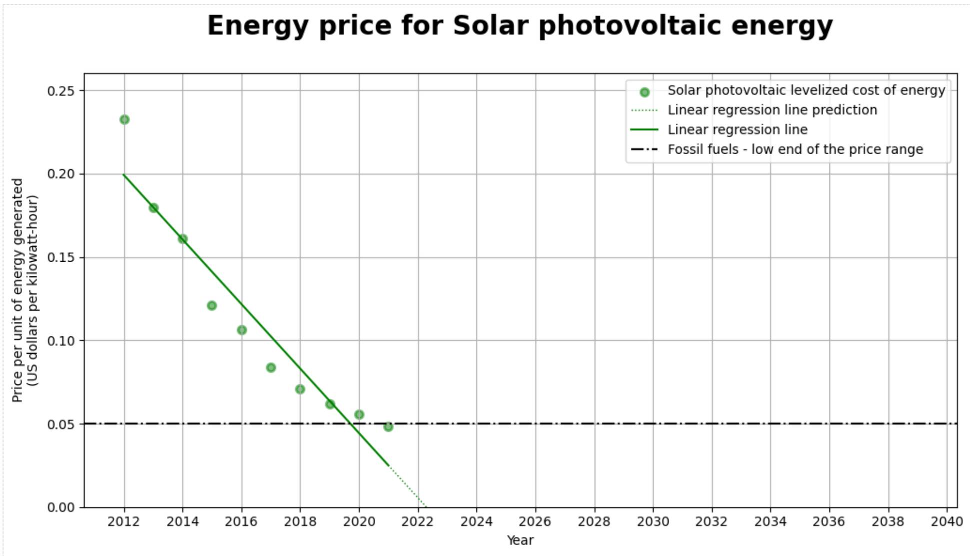

Figure 53 Energy price for solar photovoltaic energy

Conclusion: **Prices for some nonfossil fuel energy technologies are already lower than the low end of the price range of fossil fuels: solar photovoltaic energy and onshore wind energy. The price of hydropower is rising. Further investigation could find out why. The prices for the other nonfossil fuel energy technologies are all trending downwards to reach the low end of the price range of fossil fuels.** Offshore wind energy could reach this level in 2023, whereas bioenergy might need until 2036 to reach this level.

SUMMARY

CO_2 emissions & human behaviour

In this final assignment some analyses are made around CO_2 emissions.

Carbon intensity seems to be the biggest predictor of a large CO_2 output per capita. Carbon intensity can be reduced to zero if the energy mix consists of nonfossil fuel technologies. Then CO_2 output per capita is zero.

Richer people tend to emit more CO_2 according to Our World in Data[10]. As we get richer we gain access to and increase our consumption of electricity, heating, transport and other goods that require energy inputs. The strong reliance on fossil fuels until now resulted in an increase in CO_2 emissions. The analyses in this report confirm the rising correlation of Income on CO_2 output per capita.

The top emitter of CO_2 output per capita, Qatar, is also consistently found in the top 5 reducers of CO_2 output per capita.

If we want to reduce CO_2 emissions it is interesting to follow the price trends for nonfossil fuel energy technologies. Sooner or later most of the nonfossil fuel techologies will be most likely cheaper than fossil fuels.

The best summary of the topics explored is done by Max Roser in his article mentioned before: *'Scaling nonfossil fuel technologies is key to bringing down greenhouse gas emissions fast. And it has the side effects that it saves people from air pollution and it reduces energy prices - which means growing incomes and declining poverty.'*

[10] https://ourworldindata.org/emissions-drivers#richer-people-emit-more-co2