Global CO2 Emissions Analysis

Chiang Kheng He
Singapore Management University
School of Computing and Information System
Singapore
khchiang.2021@scis.smu.edu.sg

Luqman Juzaili Bin Muhammad Najib
Singapore Management University
School of Computing and Information System
Singapore
luqmanmn.2020@scis.smu.edu.sg

Mohamed Wasim So Mohamed Ali
Singapore Management University
School of Computing and Information System
Singapore
mohamedma.2020@scis.smu.edu.sg

Sharifah Afifah Binte Syed Alwi
Singapore Management University
School Of Economics
Singapore
sharifahsa.2021@economics.smu.edu.sg

Stella Sew Mei Shan
Singapore Management University
School of Computing and Information System
Singapore
stella.sew.2021@scis.smu.edu.sg

ABSTRACT

This project aims to explore the intricate relationship between CO2 emissions, Gross Domestic Product (GDP), trade volume and energy consumption on a global and continental basis. By leveraging datasets encompassing CO2 emissions, GDP, trade volume and per capita electricity consumption, our project attempts to identify possible correlations that can give us insight into better sustainable policies.

1 INTRODUCTION & PROBLEM STATEMENT

The emissions of greenhouse gases (GHGs), predominantly carbon dioxide (CO2), methane, and nitrous oxide, are a critical issue that has been recognized to contribute to more than 90% of the Earth's climate warming (Florides, 2010). As the main GHG, CO2 accounts for about 72% of the global warming effects, mostly coming from the burning of fossil fuels, the clearing of land, and the manufacture of cement. These emissions cause the Earth's atmosphere to trap more heat, leading to a gradual increase in global temperatures over the years (S. Fecht, 2021).

In 2023, the World Meteorological Organisation (WMO) reported a historic climate milestone, with global temperatures reaching their highest levels ever recorded (World Meteorological Organization, 2023). This alarming rise in temperature is accompanied by a 50% increase in greenhouse gas levels compared to pre-industrial times, indicating the urgent need for action to control and limit emissions (World Meteorological Organization, 2023). Moreover, regions around the world are experiencing increasingly frequent and severe extreme weather events.

Recognizing the urgency of the situation, the UN Climate Change Conference (COP21) convened in 2015 and formulated the Paris Agreement, a landmark international treaty where nations pledged to hold the Earth's temperature by limiting the temperature increase to 1.5°C above pre-industrial levels (The Paris Agreement, n.d.). Despite the agreement and the commitments made by many countries, we are still approaching the critical threshold of 1.5°C within the next seven years (The Straits Times, 2023). Therefore, there is a pressing need for a comprehensive analysis of CO2 emissions to develop strategies to mitigate emissions and stabilise the climate.

2 MOTIVATION

The motivation for this project stems from the urgent need to address one of our era's most pressing challenges: the rapid increase in global CO2 emissions and its profound impact on climate change. Nations are struggling to balance economic growth with environmental sustainability, and this project aims to explore the complex relationship between CO2 emissions and various factors such as trade volume, economic development (GDP), and energy consumption. By doing so, we aim to uncover insights that can guide global policies toward more sustainable paths.

While we recognize that industrial and economic growth has benefited the world, it has also led to increased CO2 emissions, which is harmful to our planet. These ongoing emissions of GHG to the atmosphere contribute significantly to global warming through the "greenhouse effect" and effects of climate feedback, further intensifying the Earth's heat disequilibrium (Anderson, 2016). This poses a significant threat to our natural ecosystems, human health, economic stability, and overall human well-being. Therefore, this report will closely examine CO2 emissions worldwide. By delving into the details of global CO2 emission patterns, the project will aid in mitigating climate change impacts and fostering a more sustainable future for all.

3 RELATED WORKS

Due to CO2 emission's impact on global warming effects, there have been many academic studies on its historical development. A widely supported framework for understanding emissions on a global scale is the Environmental Kuznets Curve (EKC) (Dina, 2004). According to the EKC, a nation's early economic growth often leads to the depletion of natural resources and overall environmental degradation, (Kurnet, 1955) as environmental degradation can only be improved with adequate economic growth.

Less developed countries lack the resources for environmental protection and economic growth can help solve the environmental problems it creates. Thus, income growth per capita, which we regard as economic growth, and environmental pollution have a positive correlation with pollution eventually tapering off as further economic growth allows for improved technology and efforts to limit degradation.

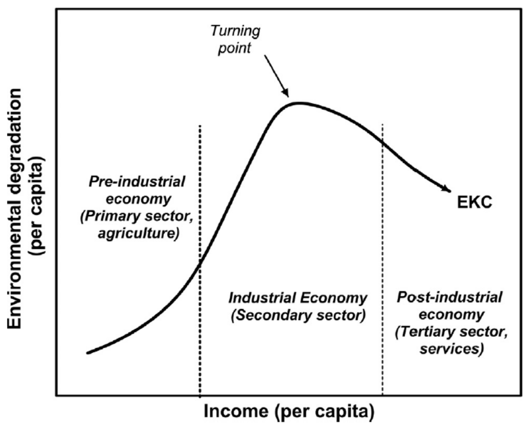

Figure 1: Environmental Kuznets Curve (EKC).

This is built upon by the Pollution Haven Hypothesis (PHH). As income levels in developing countries increase, the populace is likely more educated and aware of environmental degradation and thus demands tighter environmental protection. This pressure incentivises a shift of a nation's domestic production of pollution-intensive goods to other countries with less stringent environmental standards.

By moving to lower-income countries with laxer environmental legislation, compliance costs and regulatory burdens are minimised, allowing the now-developed country to take advantage of lower costs and less restrictive environmental policies. As a result, the exports of goods in a developed country generate the upward slope of its EKC, while, consequently, the developing countries which become importers generate the downward slope of the EKC as they eventually benefit economically and adopt more sustainable practices.

Despite much research, the relationship between carbon emissions and economic growth is still largely unclear. The causal relationship between economic growth, carbon emissions and energy consumption across the world is inconsistent, with contradictory results from the likes of Acheampong (2018), Lu (2017) and Nasreen & Anwar (2014).

According to Acheampong*, based on the data of 116 countries over the period 1990–2014* at the global and regional levels, he found that:

- With the exception of the global scale and Caribbean-Latin America region, economic growth has no causal impact on carbon emissions across the other regions. Economic growth had a negative impact on carbon emissions at the global level and Caribbean-Latin America.
- Carbon emissions positively cause global economic growth.
- Energy consumption positively causes economic growth in sub-Saharan Africa while it negatively causes economic growth in the Middle East and North Africa (MENA), Asia-Pacific, Caribbean-Latin America and global level.
- Energy consumption positively causes carbon emissions in MENA but causes carbon emissions negatively in sub-Saharan Africa and Caribbean-Latin America.
- Lastly, with the exception of MENA and the global sample, carbon emissions do not cause energy consumption. The impulse response function shows evidence of the EKC at the global scale and in Sub-Saharan Africa.

According to Lu, their paper on 1990-2012 data from 24 countries found that:

- CO2 emissions have a positive, significant effect on renewable energy consumption in 6 of the countries (Philippines, Pakistan, China, Iraq, Yemen, and Saudi Arabia), while the rest had a mix of insignificant negative and positive effects.
- Overall, a 1% increase in GDP will increase renewable energy by 0.64%. Renewable energy was significantly determined by GDP in 10 countries (India, Sri Lanka, Philippines, Thailand, Turkey, Malaysia, Jordan, United Arab Emirates, Saudi Arabia, and Mongolia).
- A unidirectional causality runs from GDP to CO2 emissions, and two bidirectional causal relationships were found between CO2 emissions and renewable energy consumption, and between renewable energy consumption and GDP.

According to Nasreen, data on 15 Asian economies from 1980-2011 found that the impact of economic growth on energy consumption is positive. Their granger causality analysis revealed a bidirectional causality between economic growth and energy consumption.

Besides looking at past research papers, our team also went on to explore the relevant CO2 emission dashboards that were published on Tableau Public, as shown in Appendix A. Many of the dashboards provide basic visualisations of total CO2 emissions by country, but they often lack in-depth analysis of the underlying factors driving these emissions. For example, they may not adequately explore the relationship between CO2 emissions, and other relevant factors, such as GDP.

Recognising this gap, our project aims to uncover the various factors influencing CO2 emissions, including GDP, energy consumption, and trade volume through data available. By doing so, we aim to provide more meaningful insights that enable policymakers, and other stakeholders to develop effective strategies for emission reduction. For instance, we could analyse how economic factors (e.g., GDP) have impacted the continent's carbon emissions. If the relationship between economic indicators and CO2 emissions is apparent, policymakers can allocate resources more effectively, ensuring limited resources are directed towards interventions with the highest potential impact. Through our project, we hope to make a significant contribution to addressing the challenge of climate change.

4 DATASET

The primary dataset for visualisation is "CO2 Emission by countries Year wise (1750 - 2022)", retrieved from Kaggle (Moazzim Ali Bhatti, 2022). It contains 59620 records of information regarding a country's CO2 emission from the year 1750 to 2020. The following table summarises the information on the dataset:

Dataset: CO2 Emission by countries Year wise (1750 - 2022)	
Source: Kaggle (Moazzim Ali Bhatti, 2022)	
Columns	**Description**
Country	Name of the country
Code	Two letter symbol code of the country
Calling Code	Phone Code of the country
Year	The year where the CO2 emission was recorded
CO2 emission (Tons)	The amount of CO2 being emitted by the country, measured in tons
Population (2022)	The population of the country in the year 2022
Area	The area of the country in km^2
% of World	The % of the world covered by the country
Density(km^2)	The number of people living per km^2 in the country

Table 1: Dataset Description.

With the following information, insights can be driven by analysing any possible correlation between a country's demographics and its CO2 emissions. However, despite the substantial amount of information in the dataset, it lacks certain information such as a country's GDP, energy consumption or trade GDP ratio, that can help substantiate the CO2 emission trends. Additionally, the information on the population of a country is only measured for the year 2022, which limits the amount of analysis that we could do to understand the population correlation or per capita values for a given year. Hence, to build upon the findings in the related works, the following datasets were also considered to augment a finalised dataset:

No.	Dataset	Description	Source
1	Population, total - The World Bank	Total Population by Countries and Years	(World Bank, 2022a)
2	World Per Capita Electricity Consumption - Kaggle	Energy Consumption by Countries and Years	(Imranktk, 2022)
3	Imports of goods and services (% of GDP) - The World Bank	Percentage of a country's (GDP) that is accounted for by imports of goods and services.	(World Bank, 2022b)
4	Exports of goods and services (current US$) - The World Bank	Monetary value (in USD) of a country's Gross Domestic Product (GDP) that is contributed by exports of goods and services.	(World Bank, 2022c)
5	GDP (current US$) - The World Bank	Gross Domestic Product (GDP) in US$ of countries across various years	(World Bank, 2022d)

Table 2: Dataset source.

We will further explore and clean the data from these 6 datasets to settle on a consolidated final dataset that contains all the required information for analysis.

5 TOOL AND RESOURCES USED

Our team utilises Python and its library package Matplotlib to clean the datasets. This method allows us to generate basic visualisations, which are crucial for spotting common data issues such as outliers and missing data. After this initial step, we proceeded with data cleaning processes to ensure the dataset was both complete and of high quality.

The project will utilise Tableau as the main visualisation tool, together with Matplotlib in the data cleaning process and D3.js as a supplementary visualisation tool. Our team chose Tableau, as it provides a user-friendly interface and a wide range of visualisation options that can be quickly generated. However, the amount of information conveyed is limited in part due to its largely static dashboard and generic options. D3.js supplements this visualisation project by providing more dynamic and interactive animations that cannot be easily achieved on Tableau or Matplotlib alone.

6 TASKS

We aim to perform several analyses to understand the multifaceted dimensions of global CO2 emissions. First, we want to conduct a general analysis of the top CO2-emitting countries to identify the leading contributors to global emissions. This is fundamental for recognising regional environmental impacts.

Following that, we examine the correlations between GDP, energy consumption, and trade with CO2 emissions on a total capita basis. The correlations between GDP and CO2 emissions will help us to understand how economic activity impacts environmental outcomes. Comparing energy consumption with CO2 emissions sheds light on the efficiency of energy use in these top-emitting countries. Additionally, analysing the trade volume (Import + Export) in relation to CO2 emissions provides insights into how trading relations might influence a country's carbon footprint. This analysis will help us pinpoint key areas for reducing emissions. A similar correlation analysis on a per capita basis will also be conducted to normalise these economic indicators against population, ensuring a fair comparison between countries with differing populations.

Both top and bottom emitters are also evaluated against population and GDP, as we wanted to examine if they play a role in their higher or lower emissions. We also want to conduct a time series analysis to examine annual CO2 emissions on a continental scale. The rate of emission increases for the top and bottom emitters by decade were also noted in this regard. This will thus show how emissions evolved over time and importantly, if certain spikes/drops had contributed to their higher/lower emissions overall. Finally, we aim to utilise D3 visualisations to examine the complex relationship between economic indicators and emissions over time. Through this advanced analysis, we intend to gain a clearer understanding of how a country's economic state is connected with its carbon emissions throughout the different years.

7 METHOD

Before working on the visualisations required for the analysis, we conducted some data exploration to understand our dataset better and also conducted data cleaning and pre-processing where required. This process is done via Python on Jupyter Notebook

The first step was to understand the main dataset, 'CO2 Emission by countries Year wise (1750 - 2022)'. Out of the 220 unique countries in the dataset, over the period of 1750 - 2022, we would like to find out how many of these values contain meaningful values. More specifically, we need to know how many countries have missing information, and the importance of the information that is missing. Throughout the years, we need to also verify the amount of CO2 Emission values that were logical such as non-zero values. Hence, we plot the average CO2 Emission across all countries across the available period of years using the Matplotlib library in Python.

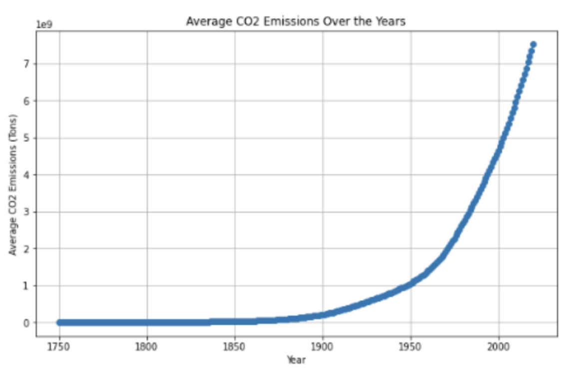

Figure 2: Average CO2 Emission Over the years

We observed that for 1750 - 1900s, most CO2 Values that were recorded were mostly 0, which may not help us a lot in our analysis. We thus decided to filter the dataset to only include the years from 1990 - 2020.

We then continued to filter out countries with at least one missing value in the dataset and found out that 31 countries out of 220 fall under this category. The number of countries was then filtered/reduced from 220 to 189.

```
missing_pop = filtered_main['Population(2022)'].isnull()
missing_area = filtered_main['Area'].isnull()
missing_perc = filtered_main['% of World'].isnull()
missing_dens = filtered_main['Density(km2)'].isnull()


# filtered_main[missing_pop]
missing_main = filtered_main[missing_pop | missing_area | missing_perc | missing_dens]
print("There are " + str(len(missing_main['Country'].unique().tolist())) + " countries with at least 1 missing value")
```

```
There are 31 countries with at least 1 missing value
```

Figure 3: Countries with at least 1 missing values

We noticed that there are also some countries with 0 CO2 emission values in the current period of years, and decided to filter them out as well. As seen below, 6 countries fall under this category.

```
zero_emission = filtered_main[filtered_main['CO2 emission (Tons)'] == 0]
zero_emission['Country'].unique()
```

```
array(['Kosovo', 'Marshall Islands', 'Micronesia', 'Namibia', 'Timor',
       'Wallis and Futuna'], dtype=object)
```

Figure 4: Countries with missing CO2 emission values

As a result, the information of the cleaned main dataset is as follows:

```
In [20]:
missing_pop = filtered_main['Population(2022)'].isna()
missing_area = filtered_main['Area'].isna()
missing_perc = filtered_main['% of World'].isna()
missing_dens = filtered_main['Density(km2)'].isna()
non_zero_emission = filtered_main['CO2 emission (Tons)'] > 0

# Drop rows with missing values
filtered_main = filtered_main[(~missing_pop) & (~missing_area) & (~missing_perc) & (~missing_dens) & non_zero_emission]
filtered_main
```

Out[20]:

	Country	Code	Calling Code	Year	CO2 emission (Tons)	Population(2022)	Area	% of World	Density(km2)
240	Afghanistan	AF	93	1990	59182404	41128771.0	652230.0	0.004	63/km²
241	Afghanistan	AF	93	1991	61609770	41128771.0	652230.0	0.004	63/km²
242	Afghanistan	AF	93	1992	62989232	41128771.0	652230.0	0.004	63/km²
243	Afghanistan	AF	93	1993	64322287	41128771.0	652230.0	0.004	63/km²
244	Afghanistan	AF	93	1994	65603889	41128771.0	652230.0	0.004	63/km²
...	...	...	...	...	...	...	...	...	...
59615	Zimbabwe	ZW	263	2016	736467042	16320537.0	390757.0	0.003	42/km²
59616	Zimbabwe	ZW	263	2017	746048675	16320537.0	390757.0	0.003	42/km²
59617	Zimbabwe	ZW	263	2018	757903042	16320537.0	390757.0	0.003	42/km²
59618	Zimbabwe	ZW	263	2019	768852126	16320537.0	390757.0	0.003	42/km²
59619	Zimbabwe	ZW	263	2020	779383468	16320537.0	390757.0	0.003	42/km²

5854 rows × 9 columns

```
In [22]:
filtered_main.info()
```

```
<class 'pandas.core.frame.DataFrame'>
Index: 5854 entries, 240 to 59619
Data columns (total 9 columns):
 #   Column               Non-Null Count  Dtype  
---  ------               --------------  -----  
 0   Country              5854 non-null   object 
 1   Code                 5669 non-null   object 
 2   Calling Code         5730 non-null   object 
 3   Year                 5854 non-null   int64  
 4   CO2 emission (Tons)  5854 non-null   int64  
 5   Population(2022)     5854 non-null   float64
 6   Area                 5854 non-null   float64
 7   % of World           5854 non-null   float64
 8   Density(km2)         5854 non-null   object 
dtypes: float64(3), int64(2), object(4)
memory usage: 457.3+ KB
```

Figure 5: Cleaned Dataset

The cleaned main dataset consists of 5854 rows with only 'Code' and 'Calling Code' with missing values. We will continue to drop those columns as it does not provide any meaningful information to the analysis.

We began to source for multiple datasets for each of the additional metrics (e.g., Population, GDP, Energy Consumption, Trade Information) and conducted the following steps. The final additional datasets were selected based on the least number of missing values

For each dataset for a particular metric, the following was conducted.

- Step 1: Find the number of countries in the cleaned main dataset and compare it against the number of countries in the additional dataset

- Step 2: Ensure that the number of countries in each dataset follows the same naming convention to ensure that no matched countries are left out.
- Step 3: Select the additional dataset with the least number of missing 'Country' and 'Year' values compared to that of the cleaned main dataset.
- Step 4: Filter out the additional dataset to only contain 'Country', 'Year' and the relevant metric (e.g. "Population" or "GDP")
- Step 5: Create a new column in the cleaned main dataset to populate the values against the filtered additional dataset.

The major challenge that we faced during the data cleaning process was to find consistent values across various datasets. With a total of 6 datasets, it is very unlikely that we can ensure that the values remain consistent and have to handle missing values.

We deal with such cases by carrying out the following steps:

1) Create a new column that indicates whether the additional column representing a new metric has any missing values or not e.g., 'GDP_missing' etc.
   a) 0: Contain missing values for the row
   b) 1: Has no missing values for the row
2) Impute the rows with missing values.
   a) If missing values only appear in some years of a given country, we impute the cell with the median value of the available data of that country.
   b) If the country has no available values across all the years, the missing values will be imputed with the median value across all countries

The rationale for doing so is that we can provide a conclusive analysis across all the different countries with the same amount of data. However, we also acknowledge the possibility of imputation values not being an accurate representation of the findings, and hence keep track of the rows with imputed values, to allow such values to be filtered out during the analysis in Tableau, if need be.

8 RESULTS & DISCUSSIONS

Following the 'Tasks' section, our team conducted a thorough thematic analysis focused on CO2 emissions, including comprehensive data visualisations. Through rigorous analysis, we gained valuable insights into the multifaceted impact of CO2 emissions from diverse perspectives.

8.1 General Analysis

Starting with a general overview of CO2 Emissions, we highlight the countries and continents that have maintained the highest average emissions throughout the historical timeline.

When looking at average CO2 Emissions, we found the United States to be the highest emitter, with a big gap between the United States and the rest of the top 10 highest emitting countries through several visualisations.

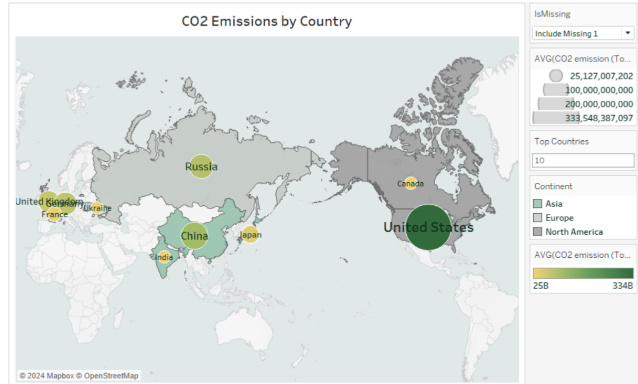

Figure 6: CO2 Emissions by Country

By employing a filled map visualisation, we effectively gauged both the geographical expanse of each top of the top 10 emitting countries and its corresponding CO2 emissions. This was achieved through a sequential colour range to represent emission levels and a proportional sizing scale using the circular shape. Continent-wise, Asia and Europe emerge as the primary regions hosting a higher concentration of top 10 emitting countries.

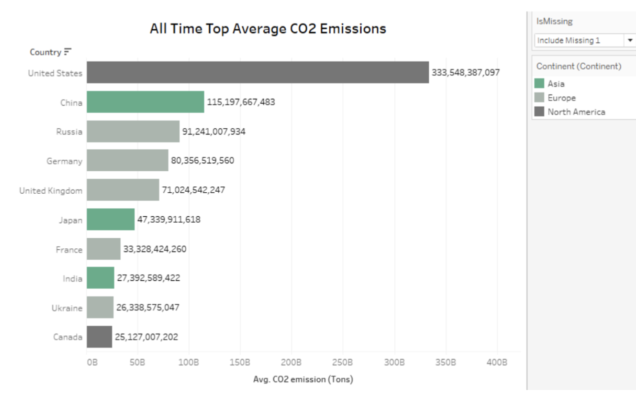

Figure 7: Top 10 CO2 Emitters

A horizontal bar chart was also employed to compare emission values more accurately, with exact values displayed. Once again, the visualisation highlights the high emission values emitted by the United States. We also notice Europe having the highest number of top emitters with 5 countries being in the Top 10. Interestingly enough, North America is the continent that has the highest emission values instead. However, as North America's emission contribution is heavily skewed towards the United States, we regard Asia and Europe as top-emitting continents instead.

Factors Correlation Score

Gross Domestic Product	0.89
Electricity Consumption	0.80
Import GDP	0.79
Export GDP	0.68
Area (km2)	0.36
Population	0.09
Trade GDP	0.05
Trade to GDP Ratio	-0.29

Figure 8: Factor Correlation Score Table

Having identified the top 10 emitting countries, we now look at the different factor variables to identify possible correlations. Average values of factors (GDP, Electricity consumption, etc) were measured against average CO2 Emission values to obtain their correlation score in a correlation matrix. GDP and Electricity Consumption had a high score of 0.8 above. In contrast, factors like population, area size and the total trade information of a country suggested a lower correlation between CO2 Emissions. We thus kept these values in mind while conducting further analysis to verify the trend of these scores.

8.2 Main Factors Correlation vs. CO2 Emissions (Total)

Moving forward, we looked into the relationship between the main factors (GDP, Electricity Consumption & Trade (Import + Export)) measured against Average CO2 Emissions on a country and continent level.

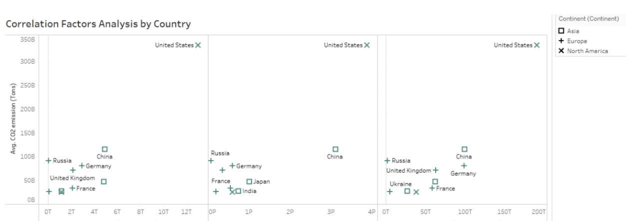

Figure 9: Correlation Factors Analysis by Country (Total)

From the visualisation above, we observe that the United States dominated all 3 fields, and is again an outlier compared to the other countries. It is worth noting, however, that Russia has a relatively lower correlation with the 3 factors and yet one of the highest emissions as compared to Germany, Japan and India.

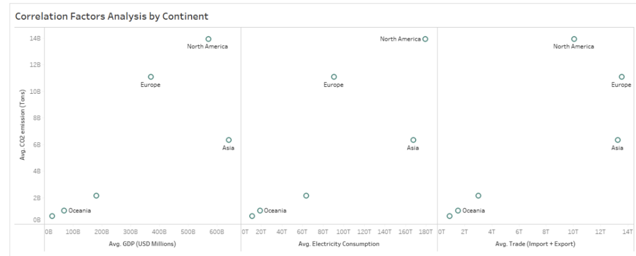

Figure 10: Correlation Factors Analysis by Continent (Total)

On a continental level, North America dominates the 3 fields again, presumably due to the United States. Interestingly, Asia seems to have the highest average GDP but has lower CO2 Emission values when compared to Europe and North America. Asia also consumes a higher amount of electricity on average as compared to Europe but emits less CO2. In terms of Average Trade, we see Europe with a higher average trade, signalling its prominent role in international trade.

8.3 Main Factors Correlation vs. CO2 Emission (Per Capita)

We also performed the same analysis on a per capita basis, to take into account the countries' population.

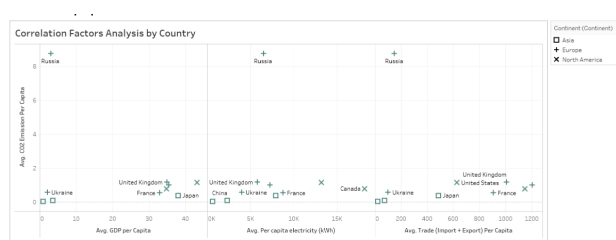

Figure 11: Correlation Factors Analysis by Country (Per Capita)

Whilst looking into CO2 Emissions per capita measured against Average GDP, Average Electricity Consumption and also Average Trade to GDP Ratio respectively, we computed entirely different results than the list of top 10 carbon emitting countries visualised earlier. Russia surprisingly emerged as the top CO2 emitter per capita despite ranking lower in terms of Average GDP and Average Electricity Consumption. This certainly begs the question of whether there may be other contributing factors that may provide insight as to why Russia is emitting significantly more CO2 per capita rather than other countries like Ukraine, which emits much lesser CO2 per capita despite ranking close to Russia in all 3 metrics.

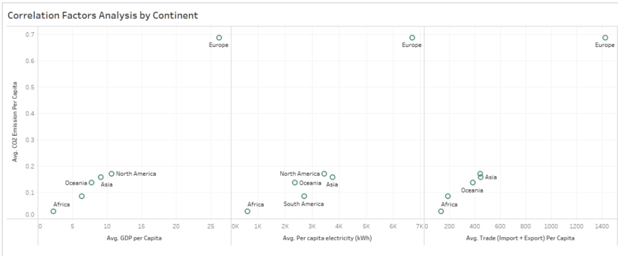

Figure 12: Correlation Factors Analysis by Continent (Per Capita)

At a continental level, we also observe that Europe has overtaken North America as the continent with the highest emission values. This is most likely due to Russia, being the largest emitter, from a per capita lens. The gap between Europe and the other continents is worth highlighting as well, as it indicates the vast difference in values.

Upon further research based on the visualisation results, we found that Russia being the world's largest country, has two-thirds of its land area covered by permafrost - a combination of soil, rocks and sand that are held together by ice. When frozen, organic carbon, which is plant material in the soil, cannot decompose or decay. However, when the permafrost thaws, microbes start decomposing this material, leading to the release of greenhouse gases such as carbon dioxide and methane into the atmosphere as temperatures rise (NASA Climate Kids, n.d.). According to one study, a 30 to 99 per cent reduction in near-surface permafrost would release an additional 10 to 240 billion tons of carbon and methane into the atmosphere and potentially put the globe "over the brink by 2100." (Conley & Newlin, 2021) Emissions-wise, a rise in the average temperature globally is set to release about six years' worth of coal and gas emissions (Welch and Orlinsky, n.d.). Thus, while Russia tops the world charts along with the US in terms of emissions from the Gas and Coal industry, other unique factors pertaining to its environmental climate are responsible for its unusually high emissions.

8.4 Top % Increase in Emissions Per Capita by top emitting countries across decades

On top of examining the CO2 Emissions of countries on a per capita basis for countries, we have also considered the percentage increase in emissions over decades. This analysis allows us to identify any potential countries experiencing high increases in emissions, despite not being among the top emitters in our general analysis.

Average CO2 Emissions by top CO2 per capita

		Decade			
Continent (..	Country (Co..	1990	2000	2010	2020
Asia	Qatar	418,703,627	807,993,033 92.97% 8.774	1,543,197,943 90.99%	2,094,572,227 35.73%
Europe	Belgium	9,635,951,901	10,895,030,308 13.07% 10.014	12,008,853,170 10.22%	12,543,142,370 4.45%
	Estonia	1,191,716,943	1,366,037,247 14.63% 9.111	1,543,668,134 13.00%	1,630,194,295 5.61%
	Germany	71,117,575,647	80,214,868,058 12.79% 10.882	88,509,205,420 10.34%	92,635,615,097 4.66%
	Luxembourg	496,271,593	594,730,800 19.84% 8.738	702,152,973 18.06%	753,685,965 7.34%
	Russia	74,714,132,973	90,240,947,395 20.78% 10.921	106,392,044,228 17.90%	115,000,000,000 8.09%
	Slovakia	2,865,990,857	3,297,509,560 15.06% 9.492	3,681,517,868 11.65%	3,869,881,084 5.12%
	United Kingdom	65,331,616,401	71,019,553,167 8.71% 10.836	76,008,796,833 7.03%	78,161,145,636 2.83%
North America	Canada	19,318,305,388	24,756,546,934 28.15% 10.346	30,461,195,671 23.04%	33,576,743,330 10.23%
	United States	273,000,000,000	331,200,000,000 21.32% 11.483	388,100,000,000 17.18%	417,000,000,000 7.45%

Figure 13: Top CO2 emissions Per cent Increase by Top Emitting Countries (Per Capita)

When we compared the countries in terms of the highest CO2 Emission per capita increases, we found out countries China and India have disappeared from the top 10 emitting countries. Therefore, this suggests that countries like China and India have high emission values due to their inherently large population sizes over time as further corroborated by our visualisation below:

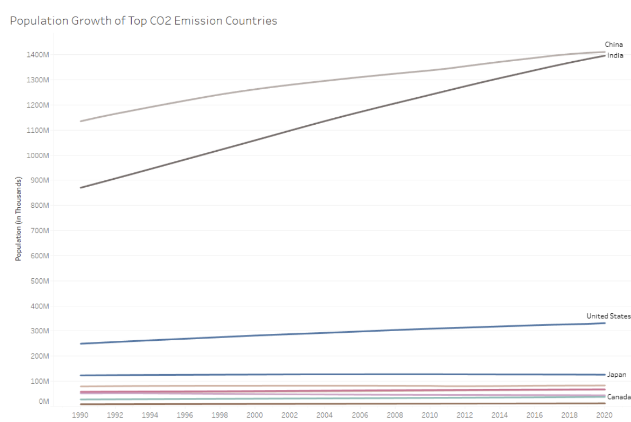

Figure 14: Population Growth of Top CO2 Emission Countries (Per Capita)

On the other hand, countries like the US, Russia, Germany and Canada remain the top emitters, which demonstrates real, increasing CO2 emissions, accounting for population size. The majority of the countries remain from Europe and North America, with Qatar, a Middle Eastern country having the highest % increase in emissions. Qatar is the largest Liquefied Natural Gas (LNG) producer and has a relatively small population (Al-Asmakh & Al-Awainati, 2018). Hence, producing for a large number of countries is likely the cause behind their CO2 emissions rapid spike.

8.5 Top % Increase in Emissions Per Capita by bottom emitting countries across decades

Average CO2 Emissions by bottom CO2 per capita

Continent (..	Country (Co..	1990	2000	2010	2020
		Decade			
Africa	Burkina Faso	12,265,625	21,954,596 78.99% 7.224	43,814,591 99.57%	64,321,172 46.80%
	Burundi	4,821,564	7,042,681 46.07% 6.791	10,050,090 42.70%	13,057,139 29.92%
	Central African Republic	5,411,362	7,633,578 41.07% 6.820	9,489,186 24.31%	10,543,960 11.12%
	Chad	6,716,478	12,256,446 82.48% 6.963	20,896,398 70.49%	26,057,722 24.70%
	Ethiopia	61,310,543	99,925,794 62.98% 7.891	180,528,718 80.66%	258,571,415 43.23%
	Gambia	4,189,418	6,942,181 65.71% 6.741	11,114,480 60.10%	13,966,136 25.66%
	Niger	16,451,681	23,269,723 41.44% 7.301	36,134,166 55.28%	46,523,337 28.75%
	Rwanda	11,375,801	16,382,924 44.02% 7.148	23,078,733 40.87%	28,684,439 24.29%
	Uganda	31,020,906	45,142,034 45.52% 7.569	78,386,879 73.64%	105,594,979 34.71%
North America	Puerto Rico	208,848	208,848 0.00% 5.320	208,848 0.00%	208,848 0.00%

Figure 15: Top CO2 emissions Per cent Increase by Bottom Emitting Countries (Per Capita)

Whilst observing the bottom few emitters with the highest % increase in emissions, we observed an emerging trend of African countries, with Burkina Faso being the country with the largest % increase in emission (99.57%). Burkina Faso is one of the poorest countries in the world, ranking "182 out of 189 countries on the United Nations Development Program's (UNDP's) 2019 Human Development Index (UNDP 2019)" (USAID, n.d.). Thus, we see that a large increase in % emissions of African countries like Burkina Faso is likely due to economic progress booming in developing countries.

8.6 Top CO2 Emissions % Increase Emitter Per Capita by Largest Countries across decades

To further compare the emission values on a per capita basis, we decided to also compare CO2 emissions among the large countries. Large countries often have a significant influence on global emissions due to their population size and economic output. Comparing the percentage increase in emissions per capita among the largest countries allows for a more nuanced understanding of their relative contributions to global emissions.

Continent (..	Country (Co..	1990	2000	2010	2020
		Decade			
Africa	Algeria	1,613,997,795	57.15% 2,536,418,950	47.69% 3,745,970,756	22.46% 4,587,131,635
Asia	China	56,579,933,815	72.03% 97,332,835,384	84.52% 179,600,000,000	31.40% 236,000,000,000
	India	14,240,739,416	68.72% 24,026,628,515	71.51% 41,208,010,378	32.05% 54,416,488,997
	Kazakhstan	8,181,976,353	20.99% 9,898,983,741	24.28% 12,302,895,412	13.05% 13,908,240,442
Europe	Russia	74,714,132,973	20.78% 90,240,947,395	17.90% 106,392,044,228	8.09% 115,000,000,000
North America	Canada	19,318,305,388	28.15% 24,756,546,934	23.04% 30,461,195,671	10.23% 33,576,743,330
	United States	273,000,000,000	21.32% 331,200,000,000	17.18% 388,100,000,000	7.45% 417,000,000,000
Oceania	Australia	8,888,645,419	39.46% 12,395,815,158	32.28% 16,397,738,879	13.65% 18,635,749,770
South America	Argentina	4,231,668,053	33.43% 5,646,390,481	31.88% 7,446,420,405	13.23% 8,431,213,004
	Brazil	5,805,128,082	56.37% 9,077,354,982	48.80% 13,507,299,569	20.22% 16,238,506,431

Figure 16: Top CO2 emissions Per cent Increase by Largest Countries (Per Capita)

Unsurprisingly, China and India returned to the top ranks, joined by Algeria and Brazil. The latter two countries experienced an increase in carbon emissions of 57.15% and 56.73% respectively, in the 2000s. In the case of Brazil, this increase in emissions was largely attributed to large amounts of deforestation which only declined after 2005 but has then picked up in the past few years. This has caused a decrease in the amount of carbon that the rainforests can absorb. For instance, the Amazon rainforest has lost its ability to absorb and store carbon by a third, compared to the 2000s (Timperley, 2018).

In the case of Algeria, it is the sixth-largest gas exporter (International Trade Administration, n.d.) and is highly reliant on its exports of oil which made up over 97% of all exports in 2013. Furthermore, it has been primarily dominated by gas-extracting industries. Omri (2013) points out that countries like Algeria tend to see a big increase in CO2 emissions when they try to modernise and grow their economies. This happens because they use a lot more energy, mostly from oil and gas. To keep up with this higher energy demand, they have to produce more oil and gas. This is needed both within the country, for homes and industries that use a lot of energy, and outside the country, to sell and get money for investing in industry. (Damette and Seghir, 2013).

8.7 Top CO2 Emissions % Increase Emitter Per Capita by Smallest Countries across decades

CO2 Emissions % Increase Per Capita by Smallest Countries

Continent (..	Country (Co..	1990	2000	2010	2020
		Decade			
Asia	Armenia	0.079	25.4% 0.099	23.1% 0.122	11.7% 0.137
	Bahrain	0.496	7.4% 0.533	4.0% 0.554	13.2% 0.627
	Bhutan	0.003	144.2% 0.008	96.0% 0.015	60.8% 0.025
Europe	Albania	0.058	23.6% 0.071	26.2% 0.090	12.0% 0.101
	Andorra	0.037	167.0% 0.098	74.4% 0.171	13.3% 0.194
	Belgium	0.953	9.1% 1.039	2.9% 1.069	1.7% 1.087
North America	Antigua and Barbuda	0.170	7.5% 0.183	15.6% 0.212	9.8% 0.232
	Bahamas	0.393	-0.2% 0.392	2.4% 0.401	4.1% 0.417
	Barbados	0.087	45.4% 0.127	36.8% 0.173	12.9% 0.195
	Belize	0.033	16.9% 0.039	13.4% 0.044	8.9% 0.048

Figure 17: Top CO2 emissions Per cent Increase by Smallest Countries (Per Capita)

When we compared the CO2 Emission % increase per capita of amongst the smallest countries, Bhutan and Andorra stood out notably with extreme values like 144.2% and 167% respectively. We thus conducted further qualitative research to gain additional insights.

The main factor that drove Bhutan to have such a great increase in carbon emissions was the deforestation that had occurred so that land could be allocated for its growing population and rapid economic development in the 2000s and early 2010s. Bhutan has an estimated annual loss of 1923 hectares of forests which is estimated to cause a 1.32 million tCO2 increase in emissions annually (WWF, n.d.)

While there is not much data that explains why Andorra experienced such an increase in carbon emissions between the 1990s and 2000s, one factor that could suggest this trend is Andorra's willingness to open up its country to tourism. In the past, it used to be isolated from the rest of Europe. Only in recent times has it built a flourishing tourist industry along with developments in communications and transportation (Wikipedia, n.d.). In fact, mobility accounts for greater than half of the energy demand of Andorra which would account for more than 47% of the country's greenhouse gas emissions (IMF, 2024). Therefore, it makes it probable that Andorra's increase in carbon emissions could be related to its recent growth in industries and economy after having opened up itself to the rest of Europe.

9 CONCLUSION & FUTURE WORKS

In conclusion, our visualisations have managed to provide invaluable insights into the complex history and landscape of CO2 emissions. Through our visualisations as well as a deeper analysis, we have managed to uncover the top-emitting countries when adjusted for population, as well as the continental contributors throughout the timeline of 1990-2020. While giving us a geographical footprint of regional emissions, we have importantly also unravelled key factors which resulted in drastic spikes in emissions over smaller time frames such as economic development in developing countries, as well as heavy emissions from key sectors such as oil production/refinery. Thus, we have overall developed a comprehensive understanding of the interplay between the various drivers of emissions growth, allowing us to identify key drivers which need/need not be prioritised in terms of improvements.

With this in mind, our field of research in terms of future work can be better improved by delving deeper into examining sector-based emissions and also other factors like economic indicators such as Gross National Income (GNI). Exploring sector-based emissions is crucial for understanding the direct sources of emissions and formulating targeted mitigation strategies. Different sectors contribute to overall emissions profiles in distinct ways due to their unique operational processes and energy needs. For example, the transportation sector contributes to emissions primarily through the combustion of fossil fuels in vehicles, ranging from personal cars to commercial aeroplanes (US EPA, 2023). With such analysis, we can then identify critical areas for improvement such as transitioning to renewable energy, enhancing efficiency, and updating regulations to support low-carbon technologies to reduce emissions.

Additionally, analysing Gross National Income (GNI) in relation to CO2 emissions offers a broader economic context beyond what GDP measures can provide. GNI accounts for all income earned by residents, including any income generated from abroad, which can influence a country's capacity to invest in green technologies and infrastructure (Rodriguez & Rathburn, 2024). Higher GNI might correlate with better technological adaptation and more efficient energy use, leading to lower emissions. By correlating GNI with emissions data, we can assess how financial factors influence a country's ability to manage and mitigate its emissions.

10 REFERENCE

Al-Asmakh, M. & Al-Awainati, N. (2018). Counting the Carbon: Assessing Qatar's Carbon Dioxide Emissions. Qatar Foundation Annual Research Conference Proceedings Volume 2018 Issue 1. https://doi.org/10.5339/qfarc.2018.eepd592

Acheampong, A. O. (2018). Economic growth, CO2 emissions and energy consumption: What causes what and where? Energy Economics, 74, 677–692. https://doi.org/10.1016/j.eneco.2018.07.022

Burkina Faso: Nutrition profile | Document | U.S. Agency for International Development. (n.d.). U.S. Agency For International Development. urlhttps://www.usaid.gov/document/burkina-faso-nutrition-profile#: :text=A%20landlocked%20sub%2DSaharan%20country,Dev elopment%20Index%20(UNDP%202019)

Conley, H A. & Newlin, C. (2021). Climate Change Will Reshape Russia. https://www.csis.org/analysis/climate-change-will-reshape-russia

D. Montoya, J. (2023) Total CO2 emissions in Andorra: Primary contributors and correlation with GDP, Economic Activity. Available at: https://www.economicactivity.org/total-co2-emissions-in-andorra-primary-contributors-and-correlation-with-gdp/

Damette, O. & Seghir, M. (2013). Energy as a driver of growth in oil exporting countries? Energy Economics, 2013, vol. 37, issue C, 193-199. https://doi.org/10.1016/j.eneco.2012.12.011

Dinda, S. (2004). Environmental Kuznets Curve Hypothesis: A Survey. Ecological Economics, 49(4), 431–455. https://doi.org/10.1016/j.ecolecon.2004.02.011

Florides, G. (2010). Global Warming: Co2 Vs Sun. In Sciyo eBooks. IntechOpen. https://doi.org/10.5772/10283

Global CO2 Emissions. (n.d.). Tableau. https://public.tableau.com/views/GlobalCO2Emissions_5/Dashboard1?:showVizHome=no

Imranktk. (2022). "World Per Capita Electricity Consumption." Kaggle. Retrieved from https://www.kaggle.com/datasets/imranktk/world-per-capita-electricity-consumption/data

International Monetary Fund. African Dept. (2024). Climate Change in Small open Economies: The Case of Andorra. https://www.elibrary.imf.org/view/journals/002/2024/058/article-A003-en.xml

International Trade Administration. (n.d.) Algeria - Oil & Gas. https://www.trade.gov/energy-resource-guide-algeria-oil-and-gas

Kuznets, S. (1955). Economic Growth and Income Inequality. The American Economic Review, 45(1), 1–28. https://assets.aeaweb.org/asset-server/files/9438.pdf

Kuznets, S. (1955). Economic Growth and Income Inequality. The American Economic Review, 45(1), 1–28. https://assets.aeaweb.org/asset-server/files/9438.pdf

Lu W. C. (2017). Renewable energy, carbon emissions, and economic growth in 24 Asian countries: evidence from panel cointegration analysis. Environmental science and pollution research international, 24(33), 26006–26015. https://doi.org/10.1007/s11356-017-0259-9

Moazzim Ali Bhatti. (2022). CO2 Emission by countries Year wise (1750-2022) [Data set]. Kaggle. https://doi.org/10.34740/KAGGLE/DSV/4202243

NASA Climate Kids. (n.d.).What Is Permafrost? https://climatekids.nasa.gov/permafrost/

Nasreen, S. & Anwar, S. (2014). Causal relationship between trade openness, economic growth and energy consumption: A panel data analysis of Asian countries. Energy Policy, 69, 82–91. https://doi.org/10.1016/j.enpol.2014.02.009

Omri, A. (2013). CO2 emissions, energy consumption and economic growth nexus in MENA countries: Evidence from simultaneous equations models. https://doi.org/10.1016/j.eneco.2013.09.003

Organisation for Economic Co-operation and Development. (2023) SUPPLEMENT TO EFFECTIVE CARBON RATES 2023. https://www.oecd.org/tax/tax-policy/effective-carbon-rates-burkina-faso.pdf

Rodriguez, P. & Rathburn, P. (2024). Gross National Income (GNI) Definition, With Real-World Example. Investopedia. https://www.investopedia.com/terms/g/gross-national-income-gni.asp

S. Fecht. (2021). How Exactly Does Carbon Dioxide Cause Global Warming? State of the Planet. https://news.climate.columbia.edu/2021/02/25/carbon-dioxide-cause-global-warming/

The Paris Agreement. (n.d.). United Nations Climate Change. https://unfccc.int/process-and-meetings/the-paris-agreement#: :text=The%20Paris%20Agreement%20is%20a,force%20on%204%20November%202016

The Straits Times. (2023). World could breach 1.5 deg C warming threshold in 7 years: Study. https://www.straitstimes.com/asia/global-co2-emissions-from-fossil-fuels-to-hit-record-high-in-2023-report

Timperley. (2018).The Carbon Brief Profile: Brazil. https://www.carbonbrief.org/the-carbon-brief-profile-brazil/ Unknown (2022) Burkina Faso: Nutrition profile: Document, U.S. Agency for International Development. https://www.usaid.gov/document/burkina-faso-nutrition-profile#: :text=A%20landlocked%20sub%2DSaharan%20country,Development%20Index%20(UNDP%202019)

US EPA. (2023). Carbon Pollution from Transportation https://www.epa.gov/transportation-air-pollution-and-climate-change/carbon-pollution-transportation#: :text=reduce%20carbon%20pollution-,Transportation%20and%20Climate%20Change,greenhouse%20gas%2C%20into%20the%20atmosphere

Welch, C. and Orlinsky, K. (n.d.) Arctic permafrost is thawing fast. that affects us all., Environment. Available at: https://www.nationalgeographic.com/environment/article/arctic-permafrost-is-thawing-it-could-speed-up-climate-change-feature

Wikipedia. (n.d.). Andorra. https://en.wikipedia.org/wiki/Andorra

World Bank. (2022a). "Population, total." Retrieved from https://data.worldbank.org/indicator/SP.POP.TOTL

World Bank. (2022b). "Net trade in goods and services (% of GDP)." World Bank Open Data. Retrieved from https://data.worldbank.org/

indicator/NE.IMP.GNFS.ZS

World Bank. (2022c). "Exports of goods and services (current US$)." World Bank Open Data. Retrieved from https://data.worldbank.org/indicator/NE.EXP.GNFS.CD

World Bank. (2022d). "GDP (current US$)." World Bank Open Data. Retrieved from https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

World Meteorological Organization. (2023). 2023 shatters climate records, with major impacts. https://wmo.int/news/media-centre/2023-shatters-climate-records-major-impacts

World Meteorological Organization. (2023). Greenhouse Gas concentrations hit record high. Again. https://wmo.int/news/media-centre/greenhouse-gas-concentrations-hit-record-high-again

WWF Bhutan. (n.d.). Climate & Energy. https://www.wwfbhutan.org.bt/_what_we_do/climate___energy/

11 APPENDIX

Appendix A: Tableau Dashboard on CO2 emission (Tableau, n.d.)