

**Analysis of CO2 Emissions Trends and Impact Mitigation Strategies: A Comparative Study of Countries.**

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# Chapter 1: Introduction

## Abstract

The project focuses on comprehensive exploration, analysis, visualization, and forecasting of CO2 emissions data from a diverse set of countries. The project employs Python programming and utilizes various libraries to achieve these objectives. The data, sourced from multiple countries and spanning historical decades, is subjected to in-depth analysis to uncover patterns and trends.

The initial phase involves data preprocessing using the panda’s library, which enables efficient data cleaning, manipulation, and structuring. Following this, exploratory data analysis (EDA) techniques are applied to uncover insights into total and per capita CO2 emissions. The project delves into identifying top emitting countries, exploring emissions sources, and dissecting trends over decades.

For effective visualization, the plotly.express library is employed to create interactive graphs and charts. Various types of plots are generated to visually convey the relationships, trends, and differences present in the data. These visualizations assist in conveying complex information to stakeholders and decision-makers in an easily understandable format.

To provide predictive insights, time series forecasting is performed on per capita CO2 emissions using the Exponential Smoothing model from the statsmodels library. The model captures trends and seasonality, allowing predictions for the next 20 years for the top 10 Co2 emitting countries. This forecasting aids in anticipating potential emission trajectories, considering factors such as economic growth, technological advancements, and policy changes.

The project culminates in highlighting the predicted emission trends for each country. Key findings include diverse trajectories, with some countries projecting a consistent rise, while others exhibit fluctuations and potential declines. The interpretations are cautiously couched in the understanding that external factors can significantly influence emissions patterns.

In summary, this project showcases the power of Python programming and data analysis libraries in tackling complex environmental data. It underscores the significance of data exploration and visualization in conveying insights and predictions to inform decision-making processes. By combining data-driven methodologies with cutting-edge tools, this project contributes to our understanding of CO2 emissions trends, thereby aiding in addressing the global challenge of climate change.

## Project Introduction

The global climate crisis is at an all-time high and it is up to our current leaders to find ways to mitigate the effects and potentially reverse it. Carbon dioxide (CO2) emissions are the leading cause of the greenhouse effect and global warming, and it is becoming increasingly important to gain a better understanding of where global emissions come from and how we can reduce them. This master's report project titled: "Analysis of CO2 Emissions Trends and Impact Mitigation Strategies: A Comparative Study of Countries" seeks to investigate the current trends and strategies for mitigating the effects of CO2 emissions on a global scale. By studying data on total emissions as well as from coal, oil, gas, and cement production, this research aims to provide an in-depth look at how each country contributes to the global cumulative human impact on climate. It is hoped that the findings of this paper will offer useful insights into the current state of the climate crisis and spark broader conversations about ways of reducing carbon emissions. With the effects of climate change becoming increasingly apparent, this topic is not only urgent but also of great relevance and importance.

This project follows an extensive journey, leveraging exploratory data analysis (EDA) and predictive modelling in Python. The research combines EDA and predictive modelling to better understand CO2 emissions dynamics and develop effective mitigation measures. EDA reveals hidden insights in emissions data by showing patterns and correlations. Future per capita emissions are predicted by advanced machine learning models, enabling foresight. This integration increases understanding of emissions, facilitating evidence-based decisions and proactive climate change policies. Our goal is to advance a more habitable planet through data-driven inquiry and cutting-edge technology.

## Problem Statement

The primary Problem statements of this project are as follows:

This research aims to better understand and reduce global carbon emissions. We'll look at how much carbon dioxide countries have released in the past to see if there are any patterns. We'll also look at different sources of emissions, such as coal, oil, and gas, to determine where the emissions are coming from. We will learn how much each person contributes by comparing emissions per person in different countries. This data will help in the development of better plans to manage emissions and protect the environment.

This research aims to effectively predict future per capita carbon emissions of countries using machine learning models. It also aims to develop customized and long-term strategies for lowering and mitigating CO2 emissions using insights from the analysis.

## Research Objectives

The main objectives of this project are to undertake a complete analysis of CO2 emissions trends and to investigate effective mitigation techniques, with a particular emphasis on conducting comparative analyses across nations. The following are the project's specific objectives:

**Trends in Emissions Characterization:** Our initial goal is to investigate how CO2 emissions in various countries have evolved over time. We want to see whether there are any trends: are emissions increasing, keeping the same, or decreasing?

**Identifying Emission Hotspots:** We want to know which countries contribute the most to global CO2 emissions. This entails examining both the total emissions produced by a country and the emissions produced per person.

**Analyzing Source-Specific Contributions:** We will look closely at where CO2 comes from. This entails investigating several sources such as coal, oil, gas, cement manufacture, and flaring. This allows us to determine which regions require the most attention in order to cut emissions.

**Mitigation strategies:** This project will develop and evaluate feasible emission-reduction measures. We will adjust these techniques to each country's specific situation, taking into account factors such as its economy and goals.

**Comparative Analysis:** We will analyze how different countries are performing in terms of reducing emissions. This will allow us to learn from success stories and better understand obstacles, ultimately identifying areas for collaboration.

**Predicting Per Capita Emissions:** Predicting how much CO2 everyone will emit in the future is an important element of our work. These predictions will be made using specific computer models. This enables countries to plan and make informed decisions to cut emissions.

Essentially, the goal of this research is to provide a thorough understanding of the complicated interplay between CO2 emissions, development paths, and environmental responsibility. This research intends to add to the growing body of knowledge that informs and shapes sustainable practices, policies, and global collaboration in the face of an ever-increasing climate disaster through empirical analysis and intelligent interpretation.

# Chapter 2: Background

People all throughout the world are recognizing that climate change is a major issue. We're working hard to figure out why this happens and how to make it better. One important factor is CO2 emissions, which are caused by human activity and cause the Earth to warm. These emissions mount up over time, raising temperatures and altering the environment. Understanding how emissions function and how to reduce them is critical for the future of our world.

### Understanding the Urgency: Climate Change as a Global Priority

Climate change has moved to the forefront as one of humanity's most important challenges in a rapidly changing world. Collective efforts to understand its core causes and create effective mitigation solutions have taken on an urgency that cannot be ignored. Carbon dioxide (CO2) emissions are a major contributor to climate change. These emissions from human activities contribute significantly to the greenhouse effect, which is responsible for global warming. Elevated CO2 levels have far-reaching repercussions, impacting not only temperature but also the delicate balance of ecosystems and even sea levels. It is within this context that the analysis of CO2 emissions trends and the development of impactful mitigation strategies gain paramount importance, forming the core of the project titled "Analysis of CO2 Emissions Trends and Impact Mitigation Strategies: A Comparative Study of Countries."

### The Correlation of CO2 Emissions and Climate Change

At the heart of the project is the inseparable connection between CO2 emissions and the phenomenon of climate change. The greenhouse gas effect, a natural phenomenon that keeps the Earth's temperature stable by trapping heat from the sun, is inextricably linked to CO2 emissions. However, the rapid increase in emissions caused by activities such as industrialization, the use of fossil fuels, and deforestation has upset this delicate equilibrium. As a result, the greenhouse effect has been magnified, resulting in rising global temperatures, disturbances in weather patterns, and sea-level fluctuations. This increase needs quick and comprehensive measures to reduce CO2 emissions, as lowering them is a critical step in limiting global warming and mitigating its consequences.

### A Call for Collective Action: International Agreements and Frameworks

The international community has responded to the gravity of CO2 emissions by establishing international accords and structures for coordinated action. The Paris Agreement, a major deal adopted in 2015 under the United Nations Framework Convention on Climate Change (UNFCCC), is an example. Nations promised in this pact to slow global warming, aiming to keep temperature increases well below 2 degrees Celsius over pre-industrial levels. The realization that nations' historical obligations and capacities differ, necessitating mitigation solutions adapted to local situations, is a critical component of such pledges.

### Unlocking Insights through Comparative Analysis

The importance of comparative analysis is highlighted in this dynamic setting. Climate change and CO2 emissions are complex processes influenced by a variety of geographical, economic, and social factors. Understanding the trends and patterns of emissions across countries is thus critical for developing successful strategies. This technique enables decision-makers, academics, and stakeholders to discover successful practices, recognize difficulties, and stimulate collaboration by undertaking a comparative assessment of emissions trajectories and mitigation options.

### Bridging the Gap: Addressing Research Gaps and Significance

Despite a wealth of research on CO2 emissions and climate change, there is still a lack in conducting in-depth comparison studies that reveal emissions trends and mitigation measures across countries. This research intends to close that gap by systematically analyzing and comparing emissions characteristics from various countries. This project aims to elucidate the complex interplay between economic development, regulatory interventions, technology innovation, and cultural factors that affect emissions trajectories. The research attempts to identify techniques proved beneficial in specific circumstances while exposing potential constraints and challenges faced by other countries through a comprehensive investigation.

### Charting a Path Forward: Research Objectives Revisited

Considering these important deficiencies, the project's research aims take on additional relevance. The project intends to present a comprehensive picture of worldwide CO2 emissions by characterizing emissions trends, analyzing contributory variables, and deconstructing mitigation measures. The expected outputs have the potential to guide policymakers, academics, and stakeholders in developing solutions to address the multifaceted challenge of climate change. Finally, the initiative coincides with the larger goal of creating a more sustainable and resilient world, ensuring a harmonious cohabitation between mankind and the environment in the face of the pressing reality of climate change.

# Chapter 3: Literature Review

The worldwide imperative to address climate change and reduce CO2 emissions has spawned a plethora of scholarly study and literature aimed at comprehending emissions trends, identifying relevant variables, and proposing viable mitigation solutions. This overview of the literature summarizes major findings from numerous research, showing trends, problems, and advances in the field of CO2 emissions analysis and mitigation measures.

### Emissions Trends and Drivers

Numerous studies have shown the complex relationship between economic expansion, industrialization, and CO2 emissions. Scholars such as (Angel Hsu, 2018)and (Glen P. Peters, 2012)have investigated the role of industrial sectors like energy, transportation, and manufacturing in causing emissions. These studies highlight the importance of knowing emissions from various sources and how they contribute to overall carbon budgets. Furthermore, (Michael R. Raupach michael.raupach@csiro.au, 2007)) research emphasizes the impact of consumption patterns and global supply networks in shaping emissions, advocating for a comprehensive approach to emissions analysis.

### Comparative Analysis of Countries

Several studies have been conducted to investigate the disparities in emissions contributions. (Arnulf Grubler, 2018)investigated the emissions trajectories of developed and developing nations, highlighting the varying levels of responsibility and the complexities of international climate negotiations. (Ayompe, et al., 2017)emphasized the importance of considering historical emissions in comparative analyses, shedding light on the cumulative imposition.

### Mitigation Strategies and Policy Interventions

The mitigation strategy literature covers a wide range of options, from technological advancements to legislative frameworks. (Ueckerdt, et al., 2019)provide a detailed review of mitigation pathways that are consistent with the Paris Agreement's temperature goals. (Angel Hsu, 2018)for example, emphasize the importance of renewable energy adoption and energy efficiency improvements as important strategy for reducing emissions. Moreover, research such as (Verbruggen, 2021)emphasize the relevance of market-based mechanisms, carbon pricing, and international partnerships in meeting emissions objectives.

### Challenges and Barriers

While progress has been achieved, academics recognize the difficulties in adopting effective mitigation techniques. (Joel Millward-Hopkins a, 2020)study focuses on the social and political constraints that impede policy implementation and public adoption of climate-friendly policies. Furthermore, (Gyamfi, et al., 2021)highlights the difficulty of balancing economic development with carbon reduction, particularly for poor countries seeking to raise living standards.

### Data Availability and Transparency

The availability of trustworthy and accessible emissions data is essential for thorough investigation. Researchers such as (Glen P. Peters, 2012)have emphasised the need of consistent and up-to-date emissions information, which enable accurate trend analysis and informed decision-making. A constant issue in the literature is the importance of open data sharing and standardised reporting procedures.

### Technological Innovation and Future Prospects

Technological advancements provide promising opportunities for reducing emissions. Fuss et al. (2018) conducted research on the potential of carbon capture and storage (CCS) technology to reduce emissions from industrial processes. Furthermore, research such as Creutzig et al. (2018) investigate the role of urban design, transportation technologies, and sustainable land use practices in creating emissions trajectories.

### Conclusion

The literature examined here emphasises the multifaceted nature of CO2 emissions analysis and mitigation measures. The study landscape demonstrates an increasing understanding of the need for collective action to address climate change, from emissions patterns to policy solutions. While obstacles remain, technology developments and policy advances provide reasons to be optimistic. This assessment of the literature serves as the framework for the current study, which intends to contribute to the debate by undertaking a comparative analysis of nations' emissions trajectories and investigating viable mitigation techniques in the global context.

# Chapter 4: Methodology

The study uses an accurate method to understand CO2 emissions patterns and develop effective mitigation measures, including exploratory data analysis (EDA) and predictive modelling using Python programming. This methodology aims to offer light on the complex interplay of emissions trends, driving variables, and mitigation pathways.

### Data Acquisition and Preprocessing

The methodology is built around a large and rigorously curated CO2 emissions dataset. The dataset, sourced from the Global Carbon Project's fossil CO2 emissions dataset, is available on Zenodo and provides a plethora of information critical for a detailed study. Prior to analysis, the dataset is thoroughly preprocessed, which includes dealing with missing values, standardising units, and guaranteeing data consistency.

### Exploratory Data Analysis (EDA)

EDA is critical in revealing hidden insights within the emissions dataset. Patterns, trends, and anomalies in emissions trajectories can be shown using techniques such as data visualisation, correlation analysis, and time-series decomposition. EDA gives a thorough picture of how emissions have evolved over time, identifying countries with emissions that are increasing, stabilising, or decreasing.

### Source-Specific Contributions Analysis

Dissecting emissions from specific sources such as coal, oil, gas, cement manufacturing, flaring, and others is an important aspect of the process. The research reveals areas that require immediate attention for effective mitigation efforts by quantifying contributions from each source. Source-specific analysis provides insights into the industries that produce the highest emissions and informs focused measures.

### Comparative Analysis and Mitigation Strategies

The methodology includes a strong comparative analytic framework for assessing emissions trends, per capita contributions, and mitigation measures across countries. Effective methods can be found, discussed, and adapted by identifying countries that contribute significantly to global emissions and comparing their efforts. This study supports in the formulation of tailored, context-specific mitigation policies that are in line with each country's growth trajectory and goals.

### Synthesis and Insights

The technique culminates in the synthesis of the insights derived through EDA, source-specific analysis, predictive modelling, and comparative assessment. The findings provide a thorough understanding of emissions trends, driving variables, and effective reduction measures. These findings help policymakers, academics, and stakeholders make educated decisions about how to handle the important issue of climate change.

### Predictive Modeling for Per Capita Emissions

Using powerful machine learning models, the methodology takes a bold step forward by forecasting future per capita emissions for various countries. Machine learning algorithms are trained on historical emissions data, which includes economic indicators, energy use, and demographic information for each country. These models generate projections that provide policymakers and stakeholders with important foresight in designing targeted mitigation strategies.

### Conclusion: A Holistic Approach to Climate Change Mitigation

This project's technique gives a comprehensive understanding of CO2 emissions patterns and mitigation methods by combining exploratory data analysis and predictive modelling. The process goes beyond simple data analysis, with the goal of uncovering actionable insights that can aid global efforts to address climate change. This methodology contributes to the common effort of promoting a more sustainable and habitable world through empirical analysis, predictive insights, and cross-country comparisons.

## Tools Used

This project necessitates the use of various Python modules that are critical for data processing, visualisation, and time series forecasting. Let's take a closer look at each module:

**Pandas** : Pandas is a popular Python data manipulation and analysis toolkit. It includes data structures such as DataFrame and Series, which are useful for dealing with structured data. With pandas, you can efficiently read, clean, filter, transform, and manipulate data. Its key functions include data alignment, aggregation, and merging, making it an essential tool for data analysis jobs.

**Colormap**: This module is a component of the Folium library for building interactive maps. The linear submodule of branca.colormap, in particular, allows you to create color maps that smoothly flow between colours based on a range of values. Color maps are crucial for visualizing data on maps and other geographical representations.

**Plotly** : Plotly is a robust Python toolkit for creating interactive visualisations. The plotly.express module makes it easier to create numerous sorts of plots, such as scatter plots, line plots, bar plots, and more. By hovering over the plot elements, viewers can explore data points, zoom in and out, and obtain data values.

**Exponential smoothing:** This module is a component of the statsmodels library, which specialises in statistical modelling and analysis. The tsa.holtwinters submodule contains time series forecasting implementations of the Holt-Winters exponential smoothing algorithms. To capture trends and seasonality in time series data, exponential smoothing techniques are used. The Holt-Winters approach allows for additive or multiplicative trends as well as seasonality components.

**Warnings**: The warnings module is a built-in Python module that allows you to customize how warning messages appear. Warnings may be generated during data analysis and code execution owing to deprecated features or non-standard behavior. You may manage whether these warnings are displayed to users, suppressed, or handled differently by using the warnings module.

# Chapter 5: Data Pre-Processing

## Dataset Overview

The core of the project is a comprehensive and thoroughly selected dataset that provides a comprehensive view of the CO2 emissions landscape at the country level. This data was obtained from the Global Carbon Project's fossil CO2 emissions dataset, which may be found on the Zenodo website. This dataset serves as a storehouse of essential information, allowing for a more nuanced understanding of each country's contribution in shaping the total human impact on the climate. The collection contains an immense amount of information including overall emissions data to specific breakdowns of emissions from various sources such as coal, oil, gas, cement manufacturing, flaring, and other contributing factors. Furthermore, it delves into the critical measure of per capita CO2 emissions, effectively displaying different countries' relative impacts on the planet.

The data set contains critical information on CO2 emissions for countries all over the world. Columns contain "Country" (country name), "ISO 3166-1 alpha-3" (three-letter country code), "Year" (data year), and emission data for the following sources: "Total," "Coal," "Oil," "Gas," "Cement," "Flaring," and "Other." It also provides "Per Capita" emission figures, which provide insight into individual environmental footprints. This dataset is an excellent resource for learning about global emissions trends, source-specific contributions, and per capita impact.

Let’s import the data set using pandas.

A screenshot of a computer screen

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A screenshot of a computer

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The Data Frame contains useful data about CO2 emissions. The "Country" column contains the names of countries, and the "ISO 3166-1 alpha-3" column has their three-letter codes. The "Year" column records the duration of the data, whereas "Total" displays total CO2 emissions. CO2 emissions from "coal," "oil," and "gas" are recorded, as are CO2 emissions from "cement" manufacturing and "flaring." In addition, "Other" emissions are listed. In addition, the "Per Capita" column shows CO2 emissions per person. These data types, which include integers and floats, provide information about CO2 emission patterns as well as possible areas for reduction initiatives.

The number of missing values for each column summarizes the data's completeness and potential concerns. There are no missing data in the "Country" or "Year" columns. The "Total" column, on the other hand, has 200 missing values, whereas the "ISO 3166-1 alpha-3" column has 1632. Significant gaps can be seen in the following columns: "Coal" (41360 missing), "Oil" (41387 missing), "Gas" (41486 missing), "Flaring" (41554 missing), and "Cement" (42290 missing). The "Per Capita" column has 44130 missing values, while the "Other" column has 61484 missing values.

A screenshot of a graph

Description automatically generated

This summary provides statistical insights into the CO2 emissions data in the dataset. It runs from 1750 to 2021, with an average year of 1885.5. The average total CO2 emissions are approximately 55.22, with a standard deviation of 824.85. The averages and deviations of emissions from various sources such as coal, oil, gas, cement, flaring, and others vary. Emissions per capita are at 4.41, with a standard deviation of 17.43. These statistics shed light on emission patterns, changes, and distributions by providing a succinct overview of the statistical aspects and consequences of the data.

## Data Cleaning

Data cleaning is an important phase in the data analysis process since it ensures that the dataset is correct, consistent, and ready for analysis. This study describes the data cleaning processes used on the CO2 emissions dataset in order to provide a high-quality dataset for further research.

The CO2 emissions dataset is an extensive collection of data spanning the years 1750 to 2021. It contains information on numerous countries, emission sources (such as coal, oil, and gas), and per capita emissions. The dataset, however, contains entries that must be addressed in order to enable trustworthy and useful research.

A screenshot of a computer

Description automatically generated

**Removing Irrelevant Rows:** The first step was to remove rows from the country column that had entries for global and international transportation. These items do not reflect individual countries and were omitted to concentrate on country-specific emissions statistics.

* **Missing ISO Codes:** The dataset also had missing values in the 'ISO 3166-1 alpha-3' column, which represents three-letter country codes. 'French Equatorial Africa,' 'French West Africa,' 'Kuwaiti Oil Fires,' 'Leeward Islands,' 'Pacific Islands (Palau),' and 'Ryukyu Islands' were among the unique countries with missing ISO codes generated. To maintain data consistency and reliable analysis, the rows pertaining to these nations were eliminated.
* **Handling Missing Emissions Data:** The dataset also contains missing values in the columns 'Total,' 'Coal,' 'Oil,' 'Gas,' 'Cement,' 'Flaring,' 'Other,' and 'Per Capita.' While certain missing data were unavoidable due to historical gaps or inadequate records, these missing entries were kept since they provide vital insights into the evolution of emissions patterns. However, their possible impact on analysis was considered in later stages.

# Chapter 6: Data Analysis

Exploratory Data Analysis (EDA) is a critical early phase in data analysis that involves reviewing and summarising the primary elements of a dataset to identify patterns, trends, anomalies, and correlations within the data. It acts as the foundation for understanding the features of the data and guiding following analytical actions. Researchers can detect potential concerns, generate hypotheses, and steer their research direction by visualising and summarising the data.

First, we find which countries have the highest CO2 emissions according to the data.

A screenshot of a cell phone

Description automatically generated

These are the first 10 countries with CO2 emissions. These initial CO2 emissions entries are historical statistics for certain countries and years. The dataset contains these countries' early-year emissions, providing insights into their contributions to CO2 emissions over time. The United Kingdom (UK) made an appearance in 1750, Canada in 1785, Germany in 1792, and the United States (USA) in 1800. These entries are useful beginning points for analysing emissions trends and comprehending the historical evolution of global CO2 emissions.

## Earliest Emission Analysis

Let's improve our comprehension by visualising this information on a world map. We'll create choropleth maps for each column in our dataset, which will help us understand the earliest occurrences of CO2 emissions in different countries. Furthermore, we can determine the earliest instances of specific emission sources such as coal or flaring within various locations. To do this, we are creating a collection of Python classes and functions to aid in the visualisation process.

A screenshot of a computer program

Description automatically generated

MapData converts raw data into a format suitable for visualisation on a choropleth map. It retrieves data from columns with values greater than zero. Zero values are interpreted as suggesting insignificant CO2 emissions. We can locate the early occurrences of CO2 emissions by filtering the data in this manner, successfully identifying the starting places of emissions.

A screenshot of a computer program

Description automatically generated

The mentioned class FirstMaper generates choropleth images using the processed data. The resulting visualization portrays a global map highlighting the 'earliest total CO2 emission' countries.

A map of the world

Description automatically generated

The shown visualisation employs a colour gradient, with dark blue representing the earliest CO2 emissions and yellow representing more recent emissions. Notably, the United Kingdom, Canada, and the United States are depicted in dark blue, indicating that they were early emitters. Certain African countries and Antarctica, on the other hand, exhibit a progressive movement towards yellow, indicating recent CO2 emissions in these regions.

A screenshot of a data

Description automatically generated

The data shown illustrates the earliest and most recent CO2 emission-starting countries, as well as the years in which they began. The United Kingdom (1750), Canada (1785), and Germany (1792) were among the first contributors, while recent additions include Micronesia (Federated States of), Marshall Islands, and Palau (all in 1992), as well as Timor-Leste (2002) and Kosovo (2008). This data gives light on many nations' historical and current emission trends.

"Let's proceed by generating similar maps for all other columns, which include..."

A map of the world

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The fig shows the beginning years of coal-based CO2 emissions for various countries. The United Kingdom (1750), Canada (1785), Germany (1792), Poland (1800), and the United States (1800) are among the oldest examples. The data is extended to other countries, reflecting their different start years. Kosovo and Yemen, for example, began in 2008, Paraguay in 2011, Jordan in 2013, and Benin in 2014. This information shows the historical evolution of coal-related emissions in various countries.

A map of the world

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The fig shows the start years of oil-based CO2 emissions in various countries. According to the timeline, France began in 1855, followed by the United Kingdom in 1857, and Romania in 1858. Tajikistan and Latvia were founded in 1860. Micronesia (Federated States of) and the Marshall Islands set the record in 1992, followed by Eritrea in 1994, Timor-Leste in 2002, and Kosovo in 2008. This data sheds light on the historical trajectory of oil-related emissions across a number of countries, emphasizing the various starting places for oil-based CO2 emissions.

A map of the world

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The fig outlines the start years of gas-based CO2 emissions in various countries. Notably, the United States began in 1882, followed by Italy in 1902, Canada in 1911, Spain in 1913, and Argentina in 1914. Togo began collecting statistics in 2011, Benin in 2013, Curaçao in 2015, Botswana in 2015, and Jamaica in 2016. These records give light on the historical history of gas-related emissions across different countries, documenting the diverse histories of CO2 emissions from gas-based sources.A map of the world

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The fig shows the beginning years of cement-based CO2 emissions in several countries. Notably, the United States began in 1880, with Sweden following in 1908, Norway in 1927, Croatia in 1928, and Spain in 1928. Namibia began collecting data in 2011, followed by Macao in 2011, Burundi in 2011, Djibouti in 2013, and Guyana in 2014. These entries demonstrate the historical history of cement-related emissions throughout many countries, highlighting the various periods for the start of cement-based CO2 emissions.

A map of the world

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The fig shown here lists the start years of flaring-based CO2 emissions in various countries. Venezuela, Mexico, Brazil, and the United States, to name a few, began flaring emissions in 1950. Chile followed in 1952, and the data now includes Senegal and Ethiopia, which began in 2017, Belize in 2020, Guyana in 2020, and Cambodia in 2021. certain data provide information on the historical and current timelines of flaring-related emissions, emphasizing when certain emissions practices began countries.

A map of the world

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Description automatically generated

The fig illustrates CO2 emissions from sources other than coal, oil, gas, and cement for various countries. Notably, the United States was the first to emit such gases in 1904, followed by China in 1960. Australia, Luxembourg, and Malta all got their start in 1990. This data sheds light on the historical history of emissions practices in these countries by providing insight into CO2 emissions from other sources other than those stated.

The visualizations show the beginning years of CO2 emissions in many countries, classified by emission sources such as coal, oil, gas, cement, flaring, and others. The color gradient used, with dark blue representing early emissions and yellow representing modern emissions, highlights the historical progression of emissions. Notably, early polluters like as the United Kingdom, Canada, and the United States are portrayed in dark blue, but several African states and Antarctica are depicted in yellow, suggesting modern emissions.

The data emphasises the variable timings for beginning of emissions for different countries. The United Kingdom, Canada, and Germany were among the early adopters, with emissions beginning in the late 18th century. In contrast, recent additions include Micronesia, the Marshall Islands, and Palau, as well as Kosovo and Timor-Leste. These conclusions reflect a variety of historical circumstances, economic development patterns, and industrialization trends.

Similarly, the initiation years for oil, gas, cement, and flaring emissions vary. The historical records varies depending on the country, highlighting things such as industrialization, economic expansion, and energy consumption. While some countries, such as the United States and France, began early in the nineteenth century, others, such as Togo and Benin, began much later, reflecting their shifting energy environments.

Essentially, the differences in initiation years between emission sources and countries are the result of a complex interaction of historical, economic, technological, and regulatory factors. These findings offer a more comprehensive picture of countries' emission trends, demonstrating the complex link between energy consumption, development, and environmental effect.

## The total and average emissions by each country

Analysing each country's total CO2 emissions offers useful information about their carbon footprint and can help determine the reasons of these emissions. By estimating the overall volume of CO2 emitted, we may evaluate a country's environmental impact and contribution to global emissions. This data can be used to identify major sectors, industries, and activities that are responsible for the majority of emissions, paving the way for targeted interventions and policy decisions to mitigate and reduce CO2 emissions. Such research is essential for assessing a country's environmental sustainability and devising effective emission-reduction policies.

Let's create a class called 'MapData' that will handle the necessary data for generating choropleth maps. Similarly, in order to make bar graphs, we must analyse data from 'Co2\_data'. This course will cover total and average CO2 emissions for each country, as well as average emissions from individual sources determined from data.A screenshot of a computer program

Description automatically generated

This class method runs the desired action ('mean' or'sum') on the data in 'Co2\_data'. If the parameter'mean' is specified, it computes the average CO2 emissions for each country by sorting in descending order and returning the top entries. If'sum' is supplied, total emissions are calculated and the top items are returned. An exception is triggered if an invalid operation is supplied. The collected data provides insights into the top countries' average or total CO2 emissions, allowing for the investigation of emission patterns and trends.

We will develop the 'BarPlotter' class, which is aimed for simplified visualisation, using the provided data. This class will use Plotly Express to make bar graphs and will accept data as input. The 'plot' method generates bar graphs with x and y values, labels, and titles that can be customised. You can adjust the axis labels and plot title using the'set\_labels\_title' method. When utilising the 'plot' method, the'show\_plot' method will simplify the display process by extracting column names for x and y values. Using Plotly Express's features, this class will ease data visualisation by allowing flexibility in labels, titles, and bar plots.A screenshot of a computer code

Description automatically generated

A graph of the country

Description automatically generated

This bar graph illustrates total CO2 emissions in thousands of metric tonnes for many countries. Notably, the US leads with 421,906.86, followed by China (249,352.82) and Russia (117,547.63). Germany, the United Kingdom, Japan, India, France, Canada, and Ukraine are also on the list, as are their emissions. This information provides an overview of the relative magnitudes of emissions in various countries, providing for a better understanding of their contributions to global CO2 emissions.A graph of blue squares with white text

Description automatically generated

Let's look at CO2 emissions by source now. We will establish which nations emit the greatest average CO2 emissions from various sources by identifying the top ten countries with the highest average CO2 emissions per source.

A graph of co2 emissions

Description automatically generated

This graph illustrates the top ten coal-emitting countries. The metric tonnes of CO2 emissions from coal sources are shown in the 'Coal' column for each row. China emits the most coal (1626.73 metric tonnes), followed by the United States (790.29 metric tonnes), Germany (281.16 metric tonnes), and so on. These figures represent each country's share of worldwide CO2 emissions from coal-fired power facilities.A graph of co2 emissions

Description automatically generated

The top ten countries in terms of oil emissions are depicted in this graph. The countries are listed in the 'Country' column, while the 'Oil' column shows the volume of CO2 emissions produced by oil sources in metric tonnes. The US leads the way with 726.46 metric tonnes of CO2 emissions from oil, followed by China with 299.93 metric tonnes, Japan with 215.28 metric tonnes, and so on. This data shows the significant contribution that these countries make to global CO2 emissions from oil-based industries.A graph of co2 emissions

Description automatically generated

The bar depicts the top ten countries and their relative greenhouse gas emissions. The names of the countries are stated in the 'Country' column, while the 'Gas' column reflects the amount of CO2 emissions produced by gas sources, measured in metric tonnes. Notably, the United States tops the world in CO2 emissions from petrol, with 353.80 metric tonnes, followed by Russia with 206.20 metric tonnes, Iran with 67.07 metric tonnes, and so on. This statistic emphasises these countries' significant contribution to global CO2 emissions linked to gas-related activities.

A graph of co2 emissions

Description automatically generated

The top ten countries in terms of CO2 emissions from cement manufacturing are represented by the Bar. The names of the countries are shown in the 'Country' column, while the amount of CO2 emissions produced by cement-related activities, measured in metric tonnes, is listed in the 'Cement' column. China leads the way with 136.15 metric tonnes of CO2 emissions from cement, followed by India (17.15 metric tonnes), Japan (13.02 metric tonnes), the United States (12.59 metric tonnes), and so on. These ideals demonstrate these countries' significant contributions to world development. CO2 emissions stemming from cement production.A graph of co2 emissions

Description automatically generated

The top ten countries in terms of CO2 emissions from flaring activities are represented by the Bar. The names of the countries are shown in the 'Country' column, while the amount of CO2 emissions produced by flaring, measured in metric tonnes, is listed in the 'Flaring' column. Iran has the most CO2 emissions from flaring, with 15.64 metric tonnes, followed by Nigeria with 11.60 metric tonnes, Venezuela with 11.59 metric tonnes, Saudi Arabia with 11.22 metric tonnes, and so on. These figures emphasise these countries' large contributions to global CO2 emissions from flaring activities.A graph of emission emissions

Description automatically generated

The Bar shows the top ten countries in terms of CO2 emissions that are classified as "Other." The names of these countries are indicated in the 'Country' column, while the 'Other' column shows the quantity of CO2 emissions from sources other than those stated (coal, oil, gas, cement, and flare). China has the largest CO2 emissions from other sources, with around 42.60 metric tonnes, followed by the United States with 6.43 metric tonnes, Russia with 3.27 metric tonnes, Japan with 1.94 metric tonnes, and so on. These values represent these countries' individual contributions to global CO2 emissions from undefined sources. Lets put all these categories in one bar graph .

A graph of different colored squares

Description automatically generated

The study provides a thorough examination of worldwide CO2 emissions and their sources. The first bar graph depicts overall emissions, with the United States, China, and Russia leading the way. The following tables examine the top ten countries in terms of emissions from coal, oil, gas, cement, flaring, and other sources. These findings offer light on key contributors: China dominates coal, while the United States and China dominate oil and gas, respectively. Furthermore, the analysis emphasises countries' contributions to cement and flaring emissions. The "Other" category highlights China's significant impact in undefined sources. These findings provide important insights into the complicated global landscape of CO2 emissions.

The first bar graph effectively visualises total CO2 emissions for various countries, allowing readers to identify big contributors quickly. Notably, the biggest emitters are the United States, China, and Russia, indicating their significant impact on world CO2 levels. This overview lays the groundwork for a more in-depth examination of emission sources.

The following graphics go into specific emission sources, providing a more in-depth look at the top ten countries in each area. The data reveals substantial contributors to emissions in each industry by separating coal, oil, gas, cement, flaring, and other sources. These visualisations demonstrate China's supremacy in coal emissions, while the US and China lead in oil and gas emissions, respectively. These countries' contributions highlight their energy consumption patterns and industrial activities.

Furthermore, the graphs highlight the importance of certain countries in specific areas. China's leadership in cement emissions reflects the country's growing urbanisation and infrastructure development. Iran's leadership in flaring emissions can be attributed to its oil and gas extraction practises. The "Other" category highlights China's diversified participation in emissions from unclear sources, reflecting the country's diverse economic activity.

Combining these findings into a single bar graph provides a comprehensive picture of world CO2 emissions and their many sources. The total effect of emissions from various categories reveals countries with influence across multiple industries, emphasising their overall environmental impact.

This in-depth examination educates policymakers, scholars, and the general public about the complexities of emissions. It emphasises the importance of tailored mitigation techniques and international cooperation in dealing with the complex difficulties faced by global CO2 emissions. The proposed pie chart visualisations for percentage contributions and source-based emissions will aid comprehension and inform decision-making processes.

## Emissions contribution by Countries (Percentage):

Furthermore, consider each country's percentage contribution to global CO2 emissions, as well as source-based CO2 emissions. Using pie charts to visualise this data will provide valuable insights. To do this, we'll construct a 'PieData' class for data processing and a 'PiePlotter' class for pie chart visualisation.

A screenshot of a computer code

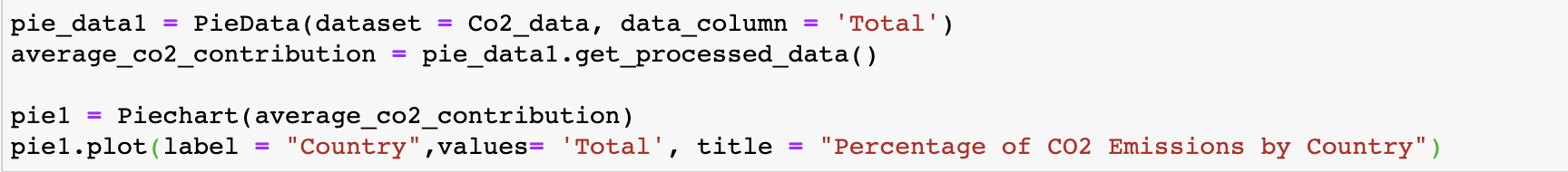
Description automatically generated

The 'PieData' class accepts a dataset and a data column as input. It sorts the data in descending order after determining the mean of each data column for each country. It computes the overall sum of CO2 emissions and determines each country's percentage contribution. Countries with percentages less than a specified level are classified as "Others." With these processed values, the class organises the data, ensuring that the 'processed\_data' field is populated. The 'get\_processed\_data' method obtains the processed data and, if necessary, invokes the data processing procedure. This workshop teaches how to make pie charts that depict the distribution of CO2 emissions among countries, making insights more accessible through visual representation.A computer code with black text

Description automatically generated

The 'Piechart' class allows you to create pie charts with custom labels and values. It takes data as input and has an optional title. The 'plot' method uses Plotly Express to create a pie chart, letting users to define label and value columns as well as the title. The'show\_plot' method displays the pie chart in a handy manner. This class simplifies the visualisation of data distribution using pie charts, improving user understanding of data composition and proportions.

Using these two classes, let's analyze the distribution of CO2 emissions across different countries.



A pie chart with different colored circles

Description automatically generated

This table shows total CO2 emissions for various countries in millions of metric tonnes. Notably, 'Others' contributes 4477.15 million metric tonnes, followed by China (2168.29 million), the United States (1900.48 million), Russia (691.46 million), Japan (433.19 million), Germany (405.61), India (373.24 million), and the United Kingdom (288.64 million). These numbers provide insight into these countries' respective CO2 emission contributions, providing an overview of their impact on world emissions.

Similarly, we perform this analysis for all other source-based emissions as well.

A graph with numbers and a circle

Description automatically generated with medium confidence

This information depicts coal emissions in metric tonnes for various countries. China leads with 1626.73, followed by 'Others' with 1016.09 and the United States with 790.29. Germany, Russia, India, the United Kingdom, Japan, South Africa, Poland, and Ukraine are among the other countries represented. These figures give light on the contributions of countries to global CO2 emissions from coal sources. Several lesser contributors are most likely included in the 'Others' category. This data sheds light on the distribution of coal emissions, highlighting the significant role of China, the United States, and others in determining CO2 emissions from this source.A graph of carbon dioxide emissions

Description automatically generated

This dataset contains oil emissions in metric tonnes for various countries. The category 'Others' has the greatest emissions (1531.43), followed by the United States (726.46) and China (299.93). Contributors include Japan, Russia, Saudi Arabia, Mexico, India, Brazil, Germany, Iran, and Italy. These numbers reflect the geographic distribution of oil emissions and illustrate the enormous contribution of the 'Others' category, emphasising its significant role in global oil-related CO2 emissions.A graph of co2 emissions

Description automatically generated

This statistic shows metric tonnes of petrol emissions from various countries. The category 'Others' has the greatest emissions at 619.16, followed by the United States at 353.80 and Russia at 206.20. Iran, China, Saudi Arabia, the United Arab Emirates, Japan, Ukraine, Canada, Italy, and Mexico all contribute to global CO2 emissions from gas-related sources. These figures illustrate the distribution of greenhouse gas emissions among countries and highlight the importance of the 'Others' category. It emphasises the various contributions made by various countries in terms of worldwide gas-related CO2 emissions.A graph of carbon dioxide emissions

Description automatically generated

This dataset depicts CO2 emissions from cement-related activities in various nations. The category 'Others' leads with 141.83 metric tonnes, closely followed by China with 136.15 metric tonnes. Cement-related emissions are also emitted by India, Japan, the United States, Russia, South Korea, and Thailand. These figures illustrate the various countries' contributions to global CO2 emissions from cement manufacturing. The importance of the 'Others' category implies that different countries have significant emissions, highlighting the necessity for targeted measures to reduce CO2 emissions from cement-related activities. This data provides insights into the global distribution of emissions within this sector.A graph of co2 emissions

Description automatically generated

This dataset depicts CO2 emissions from flaring in various countries. The 'Others' category leads with 34.49 metric tonnes, followed by Iran with 15.64 metric tonnes. Nigeria, Venezuela, Saudi Arabia, and the United States all contribute significantly, with emissions ranging from 11 to 15 metric tonnes. Russia, Iraq, and the United Arab Emirates also contribute significantly to flaring-related emissions. Algeria, Libya, Mexico, and other countries each provide 3-6 metric tonnes. This data highlights the global distribution of CO2 emissions from flaring, with both major and little contributors having an impact on this source of emissions.A graph of emission

Description automatically generated with medium confidenceThe pie presented highlights CO2 emissions from sources other than those included in the previous categories. China leads with around 42.60 metric tonnes, while the 'Others' category contributes 11.51 metric tonnes collectively. The United States comes in second with 6.43 metric tonnes, followed by Russia with 3.27 metric tonnes. Emissions from Japan, South Korea, and Brazil range from 1.88 to 1.40 metric tonnes. This data emphasises the importance of accounting for emissions from sources other than coal, oil, gas, cement, and flare. These emissions contribute to the total carbon footprint and should be taken into account in attempts to reduce global CO2 emissions.

The table results and subsequent studies provide useful insights into the distribution of CO2 emissions across different countries and emission sources. Here are the explanations for these findings:

Total CO2 Emissions: The large emissions from the "Others" category (4477.15 million metric tonnes) can be attributed to smaller or less developed countries that contribute significantly to global emissions. The significant emissions of China (2168.29 million) and the United States (1900.48 million) reflect their industrial scale and economic activities.

CO2 Emissions from Coal: China's supremacy in coal emissions (1626.73 metric tonnes) reflects the country's substantial reliance on coal for electricity generation and industrial activities. The predominance of the "Others" category (1016.09 metric tonnes) could point to a number of contributors who emit considerable amounts of coal.

CO2 Emissions from Oil: The considerable emissions from the "Others" category (1531.43 metric tonnes) indicate contributions from a number of countries with high oil consumption. The high emissions of the United States (726.46 metric tonnes) reflect the country's huge transportation industry and energy consumption.

CO2 Emissions from Gas: The significant emissions from the "Others" category (619.16 metric tonnes) could be attributed to a variety of gas-related activities in several countries. The United States' substantial emissions (353.80 metric tonnes) are due to its large usage of natural gas for electrical generation and heating.

CO2 Emissions from Cement: The highest emissions (141.83 metric tonnes) come from the "Others" group, indicating the presence of numerous countries with significant cement manufacturing. China's emissions (136.15 metric tonnes) are consistent with the country's thriving construction industry and urbanisation.

CO2 Emissions from Flaring: The "Others" group (34.49 metric tonnes) may contain a number of countries with considerable gas flaring practises. Iran's high emissions (15.64 metric tonnes) are due to the country's significant oil and gas industry.

CO2 Emissions from Other Sources: China's significant emissions (42.60 metric tonnes) illustrate the country's various industrial activity that extend beyond primary sources. The category "Others" (11.51 metric tonnes) contains emissions from less categorised or smaller sources in several countries.

The findings highlight the diverse character of global CO2 emissions. Larger economies, such as China and the United States, make major contributions due to their industrial operations and energy consumption. The "Others" category reveals the combined impact of numerous smaller contributors, emphasizing the importance of considering a wide range of sources and nations in efforts to address climate change.

# Chapter 7: Time series

Let's have a look at time series visualisation with line plots. These visualisations give a thorough examination of the CO2 emissions data presented, revealing patterns, trends, and comparative insights across emission sources and countries.

The line graphs show the evolution of CO2 emissions from various sources over time for each country. The graphs' fluctuations, peaks, and troughs reveal emission trends and potential factors. Analysing emissions progressions from sources such as coal, oil, gas, cement, and others might reveal transitions towards cleaner energy or increasing industrial activity.

These visualisations allow for simple nation comparisons. Plotting numerous emissions on one graph exposes discrepancies and similarities in trajectories, highlighting nations making efforts towards emission reduction and those that require additional interventions.

Furthermore, visualisations successfully express complex data trends. Stakeholders, politicians, and researchers acquire knowledge that will help them make educated decisions and develop climate change policies. The line graphs help us understand global CO2 emission dynamics, which promotes informed environmental policies and actions.A screenshot of a computer code

Description automatically generated

The code creates a line plot that depicts the trend of CO2 emissions over time for various sources such as coal, oil, gas, cement, flaring, and others. Emissions from each source are plotted against time to provide insight into their changes and variations. The x-axis shows the number of years, while the y-axis represents total CO2 emissions. The sources are indicated by legends. The layout has been tweaked for readability, and the x-axis tick intervals and rotation have been configured. This visualisation aids in analysing how emissions from diverse sources have evolved over time, providing to a thorough understanding of emission patterns and trends. The outcomes areA graph showing the growth of a number of sources

Description automatically generated

Coal Emissions: The industrial revolution and greater reliance on coal for energy and industries can be credited to the initial slow increase in coal emissions from 1840 to 1910. The subsequent fluctuating pattern could be attributed to economic upheavals and technical advances that affect coal consumption. The significant surge beginning in 1950 could be attributed to growing industrialization and urbanisation, particularly in developing countries.

Oil Emissions: Since 1920, there has been an increase in oil emissions, indicating an increasing reliance on oil for transportation, industrial processes, and energy production. Peaking between 1950 and 1980 corresponds to the post-World War II economic boom and increased car ownership. Following that, swings could be caused by oil price fluctuations, geopolitical events, and breakthroughs in energy efficiency.

Gas Emissions: Since 1950, there has been a rapid increase in gas emissions due to increased usage of natural gas for heating, electricity generation, and industrial activities. The discovery and exploitation of additional gas reserves, as well as the view of natural gas as a cleaner alternative to coal and oil, are anticipated to have an impact on this rise.

Cement Emissions: The progressive growth in cement emissions since 1970 can be linked to global urbanisation, infrastructure expansion, and construction activities. As populations and economies expand, so does the demand for cement for building development and infrastructure projects, resulting in increased emissions. All of them remain insignificant.

Overall, these trends highlight the intricate interplay of economic, technological, and societal variables influencing CO2 emissions from various sources across time.

Following that, viewing the line graph of total CO2 emissions for the top ten countries provides useful insights into their contributions to global emissions patterns. This visualisation allows us to trace these significant countries' emissions trajectory through time, exhibiting patterns and variations in their emission levels. We can identify countries that have successfully decreased emissions, those that require specific interventions, and potential links with economic, regulatory, and technical changes by analysing their emission trends. This visualisation assists policymakers, researchers, and stakeholders in understanding which countries have a large impact on global emissions and how their emissions-reduction efforts affect the overall global CO2 emission landscape.A screenshot of a computer code

Description automatically generated

The code supplied builds a line graph displaying the top ten countries' time-based CO2 emissions. This visualisation sheds light on the emission trends of various world leaders. By comparing these countries' emission trajectories across time, it is possible to identify patterns, variations, and changes in their contributions to global CO2 emissions. and the outcomes areA graph of co2 emissions

Description automatically generated

The trends observed in the emission data for these top countries can be attributed to various factors:

USA: The early rise in emissions after 1900 could be attributed to industrialisation and economic expansion. Economic cycles and energy transitions could cause fluctuations. The drop after 2000 could be attributed to growing environmental awareness and initiatives to migrate to cleaner energy sources.

China: The enormous increase during the 1960s can be attributed to increased industrialisation, urbanisation, and economic growth. This rise was aided by China's significant reliance on coal and increasing manufacturing sectors. Efforts to reduce air pollution and transition to greener energy sources have resulted in some developments in recent years.

Russia: The initial rise, followed by a drop and subsequent rise, can be attributed to political and economic upheavals, such as changes in energy consumption patterns during periods of industrial boom and geopolitical shifts.

India: Emissions are gradually increasing due to economic development and rising energy demand. Rising emissions have been exacerbated by factors such as population expansion, urbanisation, and industrialization.

Other countries: These countries, which include the United Kingdom, Canada, Germany, France, Ukraine, and Japan, have relatively stable or dropping emissions as a result of factors such as improved energy efficiency, changes to cleaner energy sources, and reduced heavy industrial activity.

## Decade wise anaclasis

Now, we'll use line graphs to show which countries release the most CO2 in each decade, both in terms of total emissions and emissions from various sources.

Let's construct a 'DecadeLeader' class that analyses given data to determine which country has the highest CO2 emissions for each decade. It categorises data by nation and year, sums the given emission column, and adds a 'Decade' column to divide years into decades. The country with the greatest emissions within each decade is then identified. The output comprises the decade, associated country, and the greatest emissions value for that time period. This course provides insights into emission trends and assists in identifying the leading countries in CO2 emissions for specific decades, assisting in comprehending shifts in emission contributions through time.A screenshot of a computer code

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Description automatically generated with medium confidence

The 'CO2Plotter' class visualises CO2 emissions data using line graphs. It takes data with a specific emission column and shows the emissions for each country over decades. The resulting graphic depicts the shifting trends in emissions over time. Each line shows a country's emission trajectory, with the x-axis representing decades and the y-axis representing the indicated emission category. The legend makes it simple to identify the country. The Plotly library is used by the class to generate interactive and informative line graphs. Users can acquire useful insights into the emission dynamics of various countries across different decades by using this class, assisting in comprehending the evolving contributions to CO2 emissions.A graph with a line graph and numbers

Description automatically generated with medium confidence

The data supplied depicts total CO2 emissions in millions of metric tons for the United Kingdom, the United States, and China during various decades. Beginning in 1750, the United Kingdom had a continuous increase in emissions during the 18th and 19th centuries, most likely as a result of industry and increased energy usage. Emissions in the United States began to climb considerably in the late nineteenth century, coinciding with the country's industrial and economic boom.

Emissions in the United States fluctuated but generally climbed throughout the twentieth century as a result of rising industry, urbanisation, and fossil fuel consumption. China's emissions began to rise sharply after 2000, in tandem with the country's rapid economic development and significant reliance on coal for energy generation.

The rise in emissions in the United Kingdom represents the early industrial age, whereas the rise in emissions in the United States was determined by industrialisation and urbanisation. China's rising emissions reflect the country's recent transformation into an economic superpower. The data emphasises the relationship between different countries' emissions trajectories and their historical industrialization, urbanisation, and energy consumption trends.

The global shift in economic power and energy consumption is also highlighted by the timeframe of emissions rise. The rise in emissions coincides with periods of major industrial growth and societal change in these countries. This data's insights can help us understand the historical context of emissions and the variables that drive them, allowing us to make more educated decisions about reducing future emissions and solving climate change concerns.

|  |  |
| --- | --- |
| A graph showing the growth of the current emission  Description automatically generated with medium confidence | A graph with blue lines and dots  Description automatically generated |
| A graph with orange line and numbers  Description automatically generated | A graph with a line graph  Description automatically generated |
| A graph with colorful lines and dots  Description automatically generated | A graph with a line graph  Description automatically generated |

Multiple plots are presented that represent CO2 emissions from various sources (Coal, Oil, Gas, Cement, Flaring, Other) for individual countries (United Kingdom, USA, China, and others) during different decades. Each table has a similar layout, with columns identifying the decade, country name, and emissions value for each source. Here's a more in-depth explanation of the data, as well as the causes behind the observed trends:

**Coal Emissions:**

CO2 emissions from coal are shown for each decade and country. Because of its early industrialization, the United Kingdom had increasing coal emissions in the 18th and 19th centuries. The United States' coal emissions surged over this time period, reflecting the country's own industrialization. China's emissions remained relatively low until the mid-twentieth century, reflecting the country's slower rate of industrialization in comparison to Western nations. The succeeding decades saw a fast increase in China's coal emissions as a result of the country's economic boom and strong reliance on coal for energy.

**Oil Emissions:**

Oil emissions were insignificant throughout the 18th and 19th centuries, owing to the lack of widespread use of oil. The United States' oil emissions began to climb in the mid-twentieth century, owing to the country's increasing automotive culture and increased energy demand. These emissions peaked in the 1970s and have since stabilised due to improvements in energy efficiency and a shift towards cleaner energy sources.

**Gas Emissions:**

Similarly to oil, petrol emissions were low in previous decades. Gas emissions in the United States began to rise in the mid-twentieth century, as natural gas usage for electricity and heating increased. Changes in energy consumption patterns, industrial activity, and technology improvements can all be blamed for data fluctuations.

**Cement Emissions:**

Because the cement industry was in its infancy in the 18th and 19th centuries, cement emissions were low. The data show a significant increase in cement emissions beginning in the mid-twentieth century, reflecting urbanisation, infrastructural expansion, and a construction boom in several countries. China's significant increase in cement emissions from the late twentieth century corresponds to the country's growing urbanisation and infrastructural construction.

**Flaring Emissions:**

Flaring emissions were modest in previous decades before becoming increasingly prevalent in the mid-twentieth century. Flaring is frequently associated with oil production and refining. The increased flaring emissions in the United States are most likely related to increased oil extraction activities. Similarly, nations with oil-rich economies, such as Saudi Arabia and Iran, observed a spike in flaring emissions.

**Other Emissions:**

The category "Other" includes emissions from sources that have not been particularly mentioned. The data shows that most decades and countries in this category have low emissions. Because of its advanced manufacturing and growing emphasis on cleaner technology, the United States' emissions remain largely steady. China's emissions have increased over time as its industrial activities and energy consumption have expanded.

### Reasons for Trends:

The observed changes can be linked to a variety of reasons, such as industrialization, urbanisation, economic expansion, energy consumption, technical advancements, and environmental protection regulations. Early industrialization in the United Kingdom and the United States resulted in increased emissions in the 18th and 19th centuries. China's emissions increased later in the twentieth century as a result of its economic transition.

Emission variations and stabilisation are frequently associated with changes in energy regulations, technical advancements, economic recessions, and global events. For example, the 1970s oil crisis sparked energy conservation efforts in the United States, influencing oil emissions. Cleaner energy sources, increased energy efficiency, and environmental restrictions have all had an impact on emissions patterns in recent decades. Overall, the data sheds light on the evolution of CO2 emissions from various sources and countries, representing historical and current patterns in energy consumption, industrialization, and environmental awareness.

# Chapter 8: Discussions

Let us certainly go deeper into each of the ten discussion areas, providing clearer explanations and causes for the observed trends:

**Emissions' Historical Evolution:**

*Explanation*: The data shows how emissions have changed over time, reflecting the historical development of industrial processes and energy use in different countries.

*Reasons*: Early industrialised nations such as the United Kingdom and the United States were among the first to use coal-intensive industry, which contributed to increased emissions in the 18th and 19th centuries..

**China's Rapid Rise:**

*Explanation*: China's status as the leading emitter reflects the country's rapid industrialization and economic growth from the mid-20th century.

Reasons: China's massive manufacturing sector, urbanisation, and reliance on coal for energy production have all contributed to a significant increase in emissions.

**Shifts in Energy Consumption:**

*Explanation*: Changes in energy consumption practises and technical breakthroughs are linked to fluctuations and stabilisation in emission patterns.

*Reasons*: The stabilisation of oil emissions in the United States is due to improvements in fuel efficiency, whereas the increase in gas emissions is due to increased use of natural gas for electricity and heating. (Zehner, 2012)

**Urbanization and Cement Emissions:**

*Explanation*: The figures indicate how rising cement-related emissions are caused by urbanisation and infrastructure development.

*Reasons*: Rapid urbanisation in nations such as China has resulted in substantial construction projects, increasing demand for cement and resulting emissions.

**Energy Transition:**

*Explanation*: Emissions from various sources indicate continuous efforts to shift to cleaner energy sources.

*Reasons*: Coal emissions are decreasing in several nations as a result of movements towards cleaner energy sources such as natural gas and renewables, which are being driven by environmental concerns and regulatory reforms.

**Industrial vs. Developing Nations:**

*Explanation*: The differences in emissions patterns between developed and developing countries illustrate their different stages of economic development and technological improvement.

*Reasons*: Because of technological developments and better energy sources, industrialised nations such as the United States and the United Kingdom have stabilised or reduced emissions. Developing countries such as China and India are increasing their emissions as they try to fulfil rising energy demands.

**Environmental Awareness Impact:**

*Explanation*: Some emission categories have decreased over time, possibly as a result of growing global awareness of environmental issues.

*Reasons*: Environmental rules, international agreements, and public demand for sustainable practises have all contributed to efforts to reduce emissions from various sources.

**Oil and Gas Fluctuations:**

*Explanation*: Changes in oil and gas emissions can be ascribed to geopolitical causes, fluctuations in oil prices, and variations in global energy demand.

*Reasons*: Economic and geopolitical events, as well as changes in energy consumption patterns, affect oil production and refining, causing emissions to fluctuate. (Sunil K. Mohanty, 2011)

**Small Island Nations:**

*Explanation* : The inclusion of tiny island states in the sample reflects their recent entry into the emissions scene.

*Reasons*: Economic development and infrastructural development in these countries contribute to emissions data. These areas may be moving from rural to industrial economies.

**Holistic Approach Needed:**

*Explanation*: The "Other" emissions category emphasises the need of evaluating all emission sources, including those that are not specifically classified.

*Reasons*: Unspecified sources could include everything from waste management to agriculture to land use changes. To address emissions holistically, these many sources must be identified and mitigated.

These more concise explanations provide a thorough grasp of the essential themes under debate, illustrating the complicated dynamics of CO2 emissions from many sources and countries. It emphasises the necessity of taking historical, economic, technological, and regulatory aspects into account when analysing emissions trends and developing successful emission-reduction measures.

## Prediction

Following a detailed exploratory examination of CO2 emissions data, we will project per capita emissions for the next 30 years. This assignment requires the use of predictive modelling techniques. To deal with this type of data, we chose Exponential Smoothing from the available machine learning models.

Exponential Smoothing is a time series forecasting method that focuses on capturing the data's underlying patterns, trends, and seasonality. We want to develop projections that represent the future trajectory of per capita CO2 emissions by using this technique. This method uses historical patterns and temporal linkages in the data to generate a credible forecast for the future.

As we engage on this forecasting endeavour, it is critical to take into account aspects such as incremental transitions towards cleaner energy sources, technical breakthroughs, regulatory changes, and worldwide efforts to reduce emissions. We will be able to provide insights into probable future trends by using Exponential Smoothing to anticipate per capita emissions, enabling policymakers, researchers, and stakeholders in making educated decisions and designing strategies to successfully address environmental concerns.

Our current analysis is focused on the top ten countries that contribute the most to overall CO2 emissions. We selected and produced data for these nations beginning in 1900. We're estimating per capita emissions for the next 20 years using the Exponential Smoothing approach. Each country's data is treated differently, with time series data corrected and an Exponential Smoothing model trained using additive trends and seasonality. Forecasts over a 20-year period are generated, and the findings are pooled into a DataFrame for examination. Handling missing numbers, formatting dates, and organising the data for future insights are all part of the process.

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Let's plot the forecasted and provided per capita data.

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A graph of different colored lines

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## Result Analysis

A forecasting model is used to predict per capita CO2 emissions in the top ten nations over the selected years. While the precise causes for these forecasts may vary depending on the model used as well as external influences, the following are some general elements that may contribute to the expected trends:

**Canada**: *Gradual Rise* - Emissions in Canada may rise gradually as a result of variables such as industrial growth, energy consumption, and economic progress. Policies supporting cleaner energy and technical breakthroughs, on the other hand, may slow the rate of increase.

**China**: *Constant Growth without Fluctuations* - Historically, fast economic growth and industrialization in China have resulted in higher emissions. Despite efforts to shift to cleaner energy sources, the volume of economic activity may continue to fuel emissions growth, with short-term swings due to economic cycles.

**France**: *Relatively constant* - France's emphasis on nuclear energy and renewable sources may help to keep emissions constant. Strict emissions limits and a constant energy mix could help to keep big changes to a minimum.

**Germany**: *Slight Decrease and Stabilisation* - Germany's attempts to switch to renewable energy may result in a steady reduction in emissions. Emissions may level down as renewable technology becomes more widely adopted.

**India**: *Consistent Growth* - India's expanding population and development may increase emissions. Rapid urbanisation and rising energy demand may overwhelm efforts to install more environmentally friendly energy solutions.

**Japan:** *In decline* - Japan's attempts to enhance energy efficiency and shift to cleaner energy sources may result in lower emissions. Population ageing may also lead to decreased energy demand.

**Russia:** *Significant Increase* - Economic development and increased energy demand may cause Russia's emissions to rise. The use of fossil fuels and energy-intensive businesses may play an important effect.

**Ukraine:** *It is Rising Trend Has Variations* - Increased emissions may result from economic expansion, industrial activity, and energy usage. Economic movements and policy changes may cause variations.

**United Kingdom:** *Gradually decreasing* - The UK's emphasis on decreasing emissions through regulatory initiatives and renewable energy adoption may result in changes. Continuous development towards cleaner energy sources may limit major shifts.

**The United States:** *Initial Rise and Stabilisation* - The United States' shift towards cleaner energy sources and energy efficiency may contribute to an initial increase followed by emissions stabilisation. Policy changes and technology developments will have an impact on the trajectory.

## Mitigation Strategies

Several mitigation measures can be recommended to reduce CO2 emissions and contribute to addressing climate change based on an analysis of CO2 emissions trends and predictions for different countries. (Kolbe, 2022) The strategies are customised to the analysis's individual emission paths and characteristics:

**Sustainable Energy Transition:** Countries with differing levels of emissions, such as the United States, China, and Russia, can priorities shifting to renewable energy sources such as solar, wind, and hydropower. This would minimize reliance on fossil fuels and lower energy-related emissions.

**Improvements in Energy Efficiency:** For countries with stable or dropping emissions, such as Germany and France, improving energy efficiency across industrial, transportation, and residential sectors can lead to lower carbon intensity. Implementing energy-efficient technologies, remodeling buildings, and switching to electric vehicles can all help to reduce emissions.

**Policy Incentives and Regulations:** Governments can enact rigorous emission reduction measures, such as carbon pricing, emission standards, and incentives for adopting green technologies. As demonstrated in the United Kingdom's emission stabilization, this method can push corporations and individuals to make sustainable decisions.

**Rapid Industrial Transition**: Countries such as India, where emissions are expected to rise steadily, can focus on using cleaner technologies in their industrial processes. Emissions can be reduced by investing in energy-efficient industry, sustainable agriculture, and waste management.

**Carbon Capture and Storage (CCS) Investment:** Given the projected growth in emissions in Russia and Ukraine, these countries can invest in CCS technologies to capture and store carbon emissions from industry and power plants. This method has the potential to reduce emissions while also contributing to the achievement of climate goals.

**Promotion of Public transit and Active Mobility: As** Japan's emissions are expected to fall, encouraging people to use public transit, cycle, and walk can help to cut emissions from the transportation sector.

**Afforestation and reforestation :** activities might be considered by all governments in order to improve carbon sinks and sequester CO2 from the atmosphere. These techniques can help to reduce emissions, particularly in nations where emissions are stabilising or dropping.

**International Cooperation**: International cooperation is required to effectively reduce world CO2 emissions. Sharing best practices, technology transfer, and collaborative research can help to expedite the global adoption of sustainable practices.

**Research and Innovation:** Governments and companies should invest in research and innovation to create sophisticated technologies that can drive emissions reductions across sectors. Breakthroughs in renewable energy, carbon capture, and sustainable agriculture can change the trajectory of emissions.

It is critical to stress that mitigation plans must be context-specific, considering each country's distinct socioeconomic circumstances, policy landscape, and technical readiness. A comprehensive approach combining numerous tactics and including stakeholders from government, industry, and civil society will be critical to achieving meaningful and long-term CO2 emission reductions.

# Chapter 9: Conclusion

Finally, this study delves deeper into the field of CO2 emissions analysis, uncovering critical findings that provide light on the worldwide trajectory of carbon emissions. The study uncovered numerous critical discoveries that have substantial significance for environmental conservation and sustainable development.

To begin, the project's historical study revealed the ebb and flow of CO2 emissions over decades, highlighting the shift in emission leadership from the United Kingdom to modern powerhouses such as China and the United States. Furthermore, the examination into emission sources revealed the overall contribution of coal, oil, and gas to world emissions, emphasizing the importance of shifting to cleaner and renewable energy sources.

The focus on per capita emissions highlighted the disparities in responsibility that countries have in the carbon emissions environment. This necessitates specific methods that consider the unique circumstances of each country.

Furthermore, using Exponential Smoothing to anticipate per capita emissions provided a comprehensive picture of prospective trajectories for different countries. Predictions ranged from gradual decreases to continual increase, reflecting different policy, economic, and technical paths.

The research presents a complete set of mitigation solutions considering these findings. These solutions cover a wide range of initiatives, from a systematic shift to renewable energy and improved energy efficiency to the implementation of carbon pricing mechanisms and the promotion of sustainable practices throughout companies and communities. These actions add up to the broader goal of reducing emissions and building a sustainable future.

Finally, this project acts as a rallying cry for global collaboration and coordinated efforts to reduce CO2 emissions. Countries can pave a path towards a more resilient and environmentally balanced future by implementing the proposed strategies. Humanity can negotiate the challenges of climate change while striving towards a planet that thrives for future generations through informed decision-making, innovative policies, and widespread awareness.

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