Analysis of Consumption and Emission of CO2 of the top 20% of Emitting Countries

by Christopher Brennan, Pawan Kumar, and Manu Samala

Introduction

The issue leads to increased sea-level rise, droughts, melting arctic & Antarctic, and environmental migration, among the many serious problems. CO2 is considered one of the major contributing factors leading to Global warming. Though the sources of CO2 released in the atmosphere are numerous, many of them are in balance with the natural carbon cycle. However, the excess consumption of fossil fuels due to increased industrialisation and human activities is disturbing the healthy state of our climate through global warming. In this report, we analyse the fossil fuel and renewable energy consumption trend of the top CO2 emitting countries using statistical and visual analysis tools to assess the efforts being made to combat global warming indirectly.

Motivation

Climate change is large environmental issue spanning decades and inaction results in increasing sea-levels resulting in more uninhabitable land, more intense and frequent hurricanes, and lack of ice in the artic as some examples. With this interactive project, the objective is to present data on CO2 emission and consumption using a variety of models to motivate action towards switching energy sources from fossil-fuels to renewable energies.

Methodology

In order to determine if emission data follows a Pareto distribution, we utilise descriptive statistics. Under Pareto's 80:20 rule, we assume that 80% of global CO2 emissions come from only 20% of the countries. First we calculate the total global emissions needed by totalling up the three CO2 sources. Next, the top 80% of emissions were subsetted and these countries were identified. This list is comprised of 14 countries compared to the total of 70 countries in the dataset. Thus the top 80% of emissions come from the top 20% (14/70) of countries.

We then investigate which of the three main fossil fuel sources (Oil, Gas, and Coal) contributes the most to CO2 emissions. This was implemented through a Spearman correlation. This method is ideal as the analysis does not assume normality in the data and can determine strength and direction of the linear correlation between CO2 emission by fossil fuel type and fossil fuel consumption. The total CO2 emissions for all countries was calculated in order to evaluate the impact of each fossil fuel source. It is important to look at the impact of each source because they may not produce CO2 at the same rate per unit and therefore one or more sources may play a larger role in pollution. We then calculate the percentage each source contributes to the overall CO2 emission rate and the mean emission rate. Oil, Gas, and Coal contributed 44.7%, 28.7%, and 26.6% respectively, whereas their mean emissions were 160, 106, and 209 million units. The impact, or correlation, of Oil being larger than other sources is verified when conducting the Spearman correlation of total CO2 emissions and the consumption of each source.

Visualisation Design

Our initial dataset consists of 70 countries. To visualise the CO2 emission of all these countries, we present a bar chart. Through visual analysis, we determined that a majority of countries contribute significantly less CO2 compared to a small subset of countries and thus we decide to implement the Pareto principle (80:20 rule). Under this constraint, we emphasise the top 20% of countries as they contribute 80% of total emissions. On the bar chart, the top 20% of countries are coloured in red while the bottom 80% of countries are coloured in turquoise to perceive separation in emissions. With our bar chart, we allow the user to interact with the graph by hovering over a particular bar with their mouse to show the name of the country and the total CO2 emission from 2001-2019. Through this implementation, we compare multiple countries at once and allow for precision should the user desire that data through hovering, zooming, and scrolling.

Next we present an interactive map to spatially represent the top 20% of CO2 emitters. The bubbles representing each country are red circles where the relative diameter of each bubble allows for visual comparison of CO2 emissions against the other top 20%. When initialising the interactive map, we start out with a view of all countries and can zoom in or out to focus on a particular country or region. Similar to the bar plot, when hovering over the bubble with a mouse, we see the name and total emission of that country.

To show the relationship between emission and consumption of different types of fossil fuels, we implement a matrix and scatterplot. The matrix presents the Spearman correlation values for all interactions of emission and consumption of oil, gas, and coal. These values are colour coded on a spectrum from red to blue representing -1 to 1 respectively. The colour is a visual indicator as to which interactions are heavily correlated and the direction of that correlation. We can then investigate this relationship, or other ones, further using the scatter plot. A button on the side of the graph lets the user can choose between the matrix and scatterplot. The variables from the dataset were broken down in to three categories: consumption data, emission data, and categorical variables. The user can select a variable from each group and display it with emission, consumption, and categorical variables mapped to display on the x-axis, y-axis, and colour code respectively. Clicking the dropdown menu, the user selects a variable to choose the specific interaction they want to view and the desired colour to view that data. The categorical variable selection is helpful as the data can be coloured/viewed by country or year thus presenting a large amount of data in a manageable fashion.

To best analyse net change of usage in fossil-fuels for the top 14 countries (those identified in the Pareto distribution), visual analysis of the time-series chart was used as it not only gives initial and final usage values of fossil-fuel consumption, but also gives trends or sub-trends from 2001 to 2019. This data was broken down into two graphs showing fossil fuel consumption or renewable energy consumption. The time-series plot allows us to best visualise change in year-to-year consumption of fossil-fuel/renewable energy in relation to other countries. Time from 2001 to 2019 is on the x-axis while annual fossil-fuel consumption per-capita is on the y-axis. The data is colour coded by country to easily distinguish each line. The user can watch the data plot over time to identify trends or select a particular year of interest.

We utilise time-series predictive analysis where fossil-fuel and renewable energy consumption are side-by-side to show possible change in trends for top emitting countries. For visual consistency we follow a similar style to the previous graph with by plotting predictions of fossil fuel consumption and renewable energy usage from 2020 to 2024. The data is displayed as dot plot with lines connecting the points which makes it easier to follow the trends of each country. The user can select to see all sources of energy or specific ones (e.g. oil, gas, water, etc.). From this, we can observe whether particular countries are increasing all sources of energy consumption, or whether a particular increase in an energy source corresponds to a similar decrease in another source.

Evaluation Plan

This project uses different visual analytical tools to analyze and interpret the data to get the desired information. We use the Pareto plot to determine the top 20% of countries with the highest net CO2 emission. Additionally, our correlation matrix can be used to evaluate the overall accuracy of the emission/consumption relationship as there are perfect correlations with respect to each source's consumption and its emission counterpart. This, along with the presumed positive relationship between emissions and consumption, allow for evaluation of the accuracy of the analysis.

Predictive analysis is a key analytical tool to help predict the future trend of the fossil fuel and renewable energy consumption of the top 20% net CO2 emitting countries. Here ARIMA (Auto-Regressive Integrated Moving Average) algorithm, which models a linear relationship between the data constituting the series, is used to determine the future trend of the consumption (fossil fuel and renewable energy) by these countries over the next five years.

Discussion

Through our descriptive analysis we found that the CO2 emission dataset follows a Pareto distribution. This means that a small amount of countries are responsible for an overwhelming majority of CO2 pollution. Therefore, if policy is instituted in these countries to curb CO2 pollution, it would be more effective in reducing global emissions compared with the bottom 80% of emitters. From this data, we find that there is a large gap between the the emissions of China and the USA relative to the rest of the world as shown in the bar chart.

We predict that there is a trend of some of the highest CO2 emitting countries reducing the rate at which they will consume energy from fossil-fuel sources (see ARIMA plot). Many countries will have similar consumption levels in the next 5 years as they do currently, or slightly increase compared to the past 5 years. This can also be seen in the fossil fuel line plot as a majority of countries have reduced their consumption in the past year. This can be due to social pressure and policies introduced in order to reduce the consequences of climate change. However, as the population continues to grow the countries still need to consume energy. This is why many countries are increasing their renewable energy consumption. While this level per-capita is low in almost all countries, Canada has a large reliance on renewable energy compared to others. All of the top emitting countries, except China, has a relatively consistent total CO2 emission over the past decade. However, China has seen a significant increase, more than any other country. This is most likely because they have had large exponential economic growth and energy consumption (Wang et al., 2016).

While it was not surprising that China, USA, United Kingdom, and Canada had high emissions due to their population and GDP, which have positive relationships with CO2 emissions (Pao and Tsai, 2011). It was surprising, however, that Brazil, Iran, and Indonesia had higher emission levels than Australia which wasn't in the top 20% of emitters. These countries have had rapid economic and/or population growth in recent years (Sasana, Hadi, and Eka Putri, Annisa, 2018) and thus this could explain their presence among top emitters.

Not all countries prioritise the same fossil fuel source. The US had the highest consumption in both oil and gas, however, China has a significant reliance on coal, so much so that they emit around 5 times the amount of CO2 from coal as the US does. When it comes to gas consumption Russia beats out China and thus are the fourth largest emitter.

Future Work

1. This study can be expanded by using additional variables like Country GDP, Road Infrastructure, Energy Infrastructure, Energy Source Availability, Literacy rate etc. To understand its impact on the fossil fuel and renewable energy consumption.
2. The predictive analysis can be expanded to include Bi-LSTM and the results can be compared to the Auto Arima Method used in the analysis here.
3. An analysis of the top 20% CO2 emitting country's budget allocation for the renewable energy generation and using the findings in the multivariate forecasting here can help with a more accurate model.

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Christopher Brennan
Texas A&M University

cbrennan@tamu.edu

Pawan Kumar
Texas A&M University

buddha@tamu.edu

Manu Samala
Texas A&M University

msam01@tamu.edu