Data Visualization on Global Warming by examining CO2 emissions

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***Abstract*— The continuous warming of the Earth's surface, the oceans and the atmosphere are part of global warming. The causes and effects of global warming are important to understand so that we can fight for the health of our planet. This paper uses relevant data and various visualizations to show how the temperature around the world changes and how carbon dioxide emissions affect that.**

Keywords—visualization, global warming, Tableau

I. INTRODUCTION

Our Earth is warming up. Warmer temperatures over time are changing the weather patterns and disturbing the average balance of nature, imposing risks such as hotter temperatures, more severe storms, increased drought, rising oceans, loss of species, and health risks. Studies on global warming are of great importance as they lead us to the causes of global warming and how we can fight for the health of our planet.

We will visually capture how the global temperature anomaly is increasing, making the years after 2010 in the red zone. The biggest driver of global warming is the emission of greenhouse gases, more than 90% of which are carbon dioxide (CO2) and methane. [1] In the emission of carbon dioxide, we humans have an influence. Burning fossil fuels, such as coal, oil, and natural gas, for energy consumption is the main cause of emissions, then agriculture, deforestation, and chemical reactions from specific production processes. [2] With data available for carbon dioxide emissions in the span of more than 270 years, we will visualize the relationship between temperature and CO2 emissions worldwide.

In this paper, we present our findings from the data visualizations performed in Tableau using a global warming dataset. In section II we discuss the relevant papers. In section III we will describe the dataset, in section IV we describe the visualizations, the insights gained from exploring each visualization and an overview of our results and discussions. Finally, section V highlights the conclusion of this paper.

II. CURRENT RESEARCH

Climate change is a significant challenge to human survival, and innovations to mitigate and adapt are explained in a study that aims to identify trends in climate innovation via CiteSpace visual analysis, where readers can visualize future trends and issues. They demonstrate how technological innovation increases efficiency in various fields while reducing carbon emissions. [3] Apart from the health of our planet, our health is also at great risk because of the food we eat. As different areas are heating up, things are also changing how our food is sourced. The temperature changes affect sea life and the types of crops that grow. This is described in an article published in 2018 where food gains and losses are projected to 2050 using map visualizations where we can clearly see how our dinner tables will be impacted. They also showed how elevated CO2 levels reduce essential nutrient content in plants, such as zinc, protein, and iron. [4] The damage to our food is directly connected to polar vortexes, increased heat waves and ice loss. The Arctic has warmed nearly four times faster than the global average over the past four decades and if emissions continue to rise, the Arctic could be ice-free by 2040. Using several observational datasets and visualizations, a study has shown that during 1979–2021, significant portions of the Arctic Ocean were warming at least four times as fast as the global average especially in the sea areas near Novaya Zemlya. [5]

III. MATERIALS AND METHODS

In the following, we will answer the questions about how much temperature has changed since 1750, how much CO2 emissions have risen and is the relationship between the temperature anomaly and carbon emissions linear. We will elaborate on the period when global warming started and how it relates to CO2 emissions. Finally, we will dive deeper and compare carbon emissions from different countries, emphasizing which countries contributed to solving the problem with significant carbon emissions. Each conclusion is mapped on a specific visualization using various components available in Tableau.

To obtain a dataset for average monthly temperatures by city, it was necessary to combine two datasets. In the first, downloaded from the official site of Kaggle [6], the data is aggregated monthly for a total of 3605 cities worldwide. The dates vary from 01.11.1743 to 30.09.2013. Since such data are up to 2013, the dataset from the Physical Sciences Laboratory [7] was used, which has data up to 01.12.2017. By concatenating the two datasets, we have data for average monthly temperatures from 01.11.1743 to 01.12.2017 for 3605 cities. To analyze how carbon dioxide affects decreased or increased temperatures, a dataset of carbon dioxide emission values by year and country was used, which was downloaded from Kaggle. [8] Carbon dioxide emission by country is measured as the total amount of carbon dioxide in tonnes emitted by the country as a result of all relevant human activities, production and consumption, divided by the country's population. The data ranges from 1751 to 2017 for 153 states. The third type of data used is for temperature anomaly, downloaded from Berkeley Earth. [9] Such values represent the deviations from the average temperature, that is, how much the temperature has increased or decreased from 1750 for 1197 different cities, varying from 16.01.1750 to

17.08.2021. Each dataset was imported to Tableau as a CSV file. The files for monthly average temperatures were partitioned, and the union was used to merge them into a single table. Tables were joined with one-to-many relationships, where the city or country IDs were used as foreign keys because each data point is for a specific city or country. A one-to-one relationship was used for mapping the table with city information, with the table containing the latitude and longitude for each city. Each temperature is in degrees Celsius, and the emissions are measured in tons, so an appropriate suffix sign was added to the temperature and CO2 columns.

IV. Results and Discussion

Each of the data visualizations belongs in a specific section. For example, we have section for visualizations aggregated on a global level, then visualization of data aggregated by the country where the filter by country is available and where we can track the data for a specific country, and a section for summarized conclusions obtained using calculations on the entire dataset.

A. Temperature Anomaly World Map

A positive temperature anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates that the observed temperature was cooler than the reference value. Having data for temperature anomaly from January 1750 until August 2021, it can be seen that the average temperature anomaly in 1750 globally was -0.62°, and in 2020 it was 1.42°. To visually capture in which part of the world we have the most significant deviation from the average temperature, we will use a map in Tableau. We will consider the latest available temperature anomaly data, and using the latitude and longitude for a city, a map is created, where each point represents a corresponding city. As given in Graph 1, the temperature anomalies per city vary from -0.098° to 3.903°. Using different tones of red colours it can be noted in which areas we have the strongest tones of red colour or where we have the highest temperature anomaly. We can spot dark red colours around cities in Russia. The Center for strategic and international studies stated that Russia is warming 2.5 times faster than the rest. In 2020, regions in Russia experienced the hottest temperatures on record, leading to forest fires that emitted one-third more CO2 than in 2019. [10]

B. Graphic for Temperature Anomaly and CO2 Emissions

Graph 2 shows data for temperature anomalies and carbon dioxide emission in tons. The linear dependence between the rise in temperatures and the emission of carbon dioxide is seen; that is, the emission of carbon dioxide directly affects global warming. Although global warming is present, the biggest dilemmas are when exactly global warming starts and what the cause is. In the 1830s, the level of carbon dioxide was 2,200,602,064 tons, which is a pre-industrial value. And, in 1900, it was already 44,821,067,136 tons, which is a difference of 2,620,465,072 tons. This increase in carbon dioxide during the 19th century is slight by today's standards. Now takes only seven years for our consumption of fossil fuels to reach the same amount of additional carbon dioxide in the atmosphere.

C. Graphic for Average Monthly Temperatures

In Graph 3, we have the average monthly temperatures by country. We can use two filters, by country and by date, so in this way, for a specific country, temperatures can be monitored for a certain period. The maximum average temperature is also marked, and on average the maximum temperature for each country was reached in the last 20 years, that is, after the year 2000. Despite the relatively small area of North Macedonia, the climate is diverse. The hottest month in North Macedonia is July, and the coldest is January. As shown in Graph 3, the hottest month from 1750 was July 2012. The CO2 emission in this country has a yearly change of 1.62%, and most of the emissions are due to the power industry. In April 2021, the Republic of North Macedonia committed to an 82% reduction in net greenhouse gas emissions in 2030 compared to 1990 in the Paris Agreement. This commitment was described as a bold climate target. [11]

Fig. 1. Temperature anomalies in 2021 for different cities around the world.

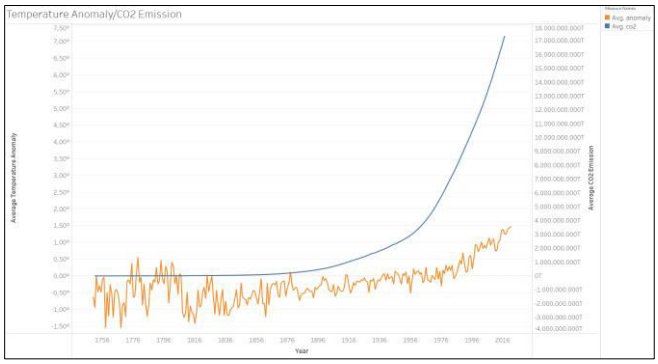

Fig. 2. Graphic for Temperature Anomaly and CO2 Emissions

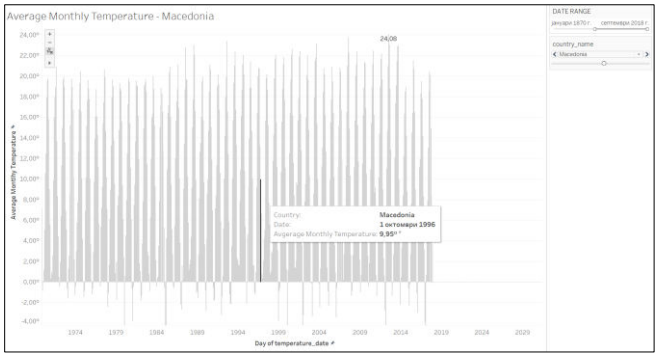

Fig. 3. Graphic for Average Monthly Temperatures

D. Graphic for CO2 Emissions

For each country, we also have an overview of the carbon dioxide emission given in tons and the period for the industrial revolution, which has a significant impact on the carbon dioxide emission, and visually we can notice how the level of carbon dioxide emission is drastically increased after the

industrial revolution, given in Graph 4. Since the industrial revolution, humans have expelled large amounts of carbon dioxide into the atmosphere. This has triggered manufactured warming on planet Earth. On the other hand, industrialization has allowed developing countries the opportunity for development and societal growth that would otherwise be impossible. Still, industrialization has also created an environmental impact on our world.

In Graphs 5 and 6, we can distinguish between the carbon dioxide emission for the UK and the US, and it is noted that the US has a significantly higher emission. The UK has committed to reducing emissions faster than other developed countries, with a target of 68% reductions by 2030 compared to 1990 emissions. Around 20% of UK CO2 emissions in 2017 came from burning coal, oil and gas to generate electricity. This is down from 34% in 1990. The oil used to generate electricity has also declined, from 11% of production in 1990 to less than 1% today. They have been mainly replaced by gas, wind and bioenergy. [12] For the United Kingdom, it is seen that although the curve for carbon dioxide rises linearly, from 1971 to 2021, emissions have increased from 51,000 to 77,000 megatons of carbon dioxide, and in the United States over the same period emissions have climbed from less than 158,000 megatons to 400,000 megatons of carbon dioxide.

E. Global Calculations

To determine which decade is the warmest since 1750, it is necessary to aggregate the data by decade and then select the maximum. From the data, we can conclude that the warmest decade since 1750 is 2010-2020. The six warmest years are all after 2015, with the top three being 2016, 2019 and 2020. 2020 has been labelled as one of the three warmest years on record, surpassing 2016, the previous warmest year, according to a consolidation of five leading international datasets by the World Meteorological Organization. [13]

We calculated that the most deviation from the average monthly temperature is in cities in Russia and Finland, as shown in Figure 7. During the last 100 years, the warming in Russia was about 1.29°, while global warming was 0.74° according to the fourth assessment report of the IPCC, [14] which shows that the warming of the Russian climate is happening at a faster pace than the average.

According to the most significant carbon dioxide emissions, the first three places are the United States of America, China, and Russia. The most important sources of CO2 emissions in the US are transportation, industry, and electricity generation, in 2020. Also, the US economy relies heavily on the transportation sector, which burns oil for trucks, ships, trains, and planes. Another major contributor to US CO2 emissions is industry, which burns fossil fuels for energy. [15] China's primary source of CO2 emissions is fossil fuels, notably coal burning. About 58% of the total energy obtained in China was from coal alone in 2019. Because coal is rich in carbon, combustion in China's power plants and industrial plants, and boilers release large amounts of CO2 into the atmosphere. [16] Also, China is one of the largest oil importers, which contributes to significant CO2 emissions through the use of motor vehicles. [17] Russia has one of the world's largest deposits of natural gas, and natural gas is the country's primary energy and electricity generation source. Coal, widely used in Russia's chemical industry and electricity generation, contributes significantly to Russia's CO2 emissions.[18]

The most significant step to tackle climate change came with the Paris Agreement in December 2015, whose central goal includes continuing efforts to limit the rise in global temperature to 1.5 °C relative to pre-industrial levels. At the 21st Conference of the Parties in December 2015, 195 countries adopted the Paris Agreement. [19]

Global warming has already reached 1°C above pre-industrial levels. By 2006-2015, human activities warmed the world by 0.87°C (±0.12°C) compared to pre-industrial times (1850-1900). Given that the global temperature is currently rising by 0.2°C (±0.1°C) per decade, human-induced warming reached 1°C above pre-industrial levels around 2017. If the current rate of warming continues, the world will reach global warming of 1.5 °C around 2040. Under the 2015 Paris Agreement, countries agreed to reduce greenhouse gas emissions to keep the increase in global average temperature below 2 °C relative to pre-industrial levels.

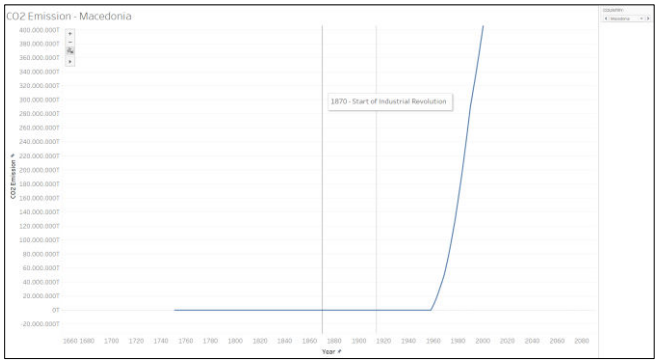

Fig. 4. Graphic for CO2 Emission in North Macedonia

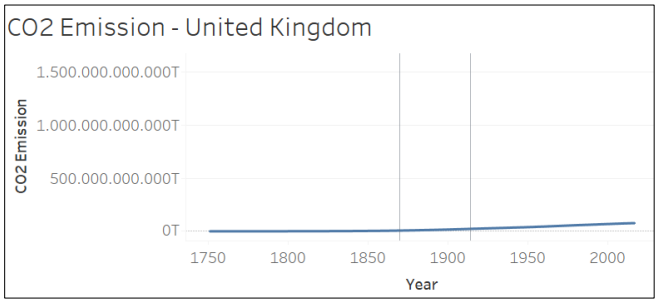

Fig. 5. Representation for CO2 Emission in the United Kingdom

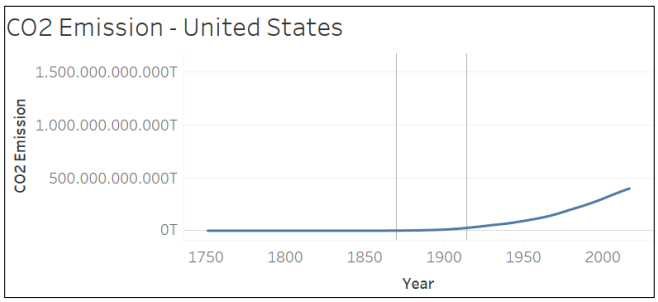

Fig. 6. CO2 Emissions in the United States

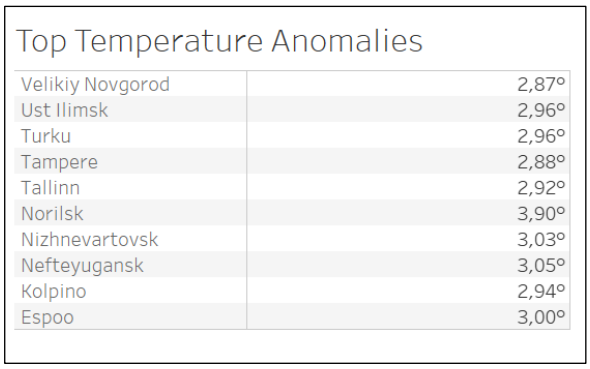

Fig. 7. Top Average Temperature Anomalies by City

We have shown the literal planet-warming with the increasing temperature anomalies and red zone cities. Warming associated with carbon dioxide emissions agrees well with our visualizations. The visualized relationship between temperature and carbon dioxide emissions gives us the direction we should focus on contributing to slowing the process of global warming. More prominent countries have more significant contributions, and we have compared the emissions between countries showing that carbon dioxide emissions are decreasing with the right commitments. Human activities, especially emissions of greenhouse gases, are the dominant cause of observed warming. Knowing that human activities are the primary driver of global warming helps us understand why our climate is changing and how we can all contribute to avoiding worse climate change harms. This means investing in a clean energy economy, transforming transportation, and shifting to a lower-carbon lifestyle.

V. Conclusion

The global warming we are experiencing is caused by human activities resulting in greenhouse gas emissions such as carbon dioxide. According to the Intergovernmental Panel on Climate Change, global warming is an increase in the average temperature of the Earth's surface due to the effect of greenhouse gases. Hence, monitoring and managing carbon dioxide emissions are essential to maintain a low carbon dioxide emission level. Through the visualizations created in Tableau, global warming conclusions are made about how temperatures are increasing more and more. It can also be seen how carbon dioxide emission affects the world's temperatures linearly. By aggregating existing data globally, we visualize historical periods that contributed to global temperature increases, such as the industrial revolution. By reviewing the carbon dioxide emissions by country, one can understand who affects global warming and, thus, which can contribute the most to reducing the crisis.

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