Effect of Carbon Dioxide (CO_2) Emission on Global Temperature Changes

by

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A REPORT

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1 Abstract

Climate Change has been a hot issue since the 1990s. Although some might not understand it properly, the effects are becoming more drastic every year. CO_2 is considered as the main greenhouse gas which has increased tremendously in the recent decades due to industrial development. The effect of greenhouse gasses on climate change is apparent in the numerous studies performed in the last few decades. This study will be targeting data from 1850 to 2012. Annual and cumulative CO_2 emission per country will be investigated. Temperature reading and changes during this period will also be analyzed to emphasize changes in the climate. The data will be visualized on a world map and comparisons will be made by different visual aids and patterns.

2 Introduction

Global warming, also referred to as climate change, is the observed century-scale rise in the average temperature of the Earth's climate system and its related effects. Multiple lines of scientific evidence show that the climate system is warming. Many of the observed changes since the 1950s are unprecedented in the instrumental temperature record which extends back to the mid-19^{th} century, and in paleoclimate proxy records covering thousands of years.

In 2014, the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report concluded that "It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20^{th} century"[1]. The largest human influence has been the emission of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Future climate change and associated impacts will differ from region to region. Anticipated effects include increasing global temperatures, rising sea levels, changing precipitation patterns, and expansion of deserts in the subtropics. Warming is expected to be greater over land than over the oceans and greatest in the Arctic, with the continuing retreat of glaciers, permafrost and sea ice. Carbon dioxide (CO_2) is considered to be one of the primary greenhouse gases (GHGs). These gases warm the surface and the atmosphere of the earth. Ramanthan and Feng (2009) illustrated how carbon dioxide traps the long wave radiation from the incident solar radiation. They described how the CO_2 is acting as a heat blanket to the world, and with increasing the CO_2 with time, this blanket is getting thicker, and the planet is accumulating this excess energy which is heating the planet and the atmosphere [2]. Moreover, Solomon et al. (2009) demonstrated how the global average temperature is growing with cumulative CO_2 concentration in the atmosphere and concluded that this change could be irreversible [3].

Other likely changes include more frequent extreme weather events such as heat waves, droughts, heavy rainfall with floods and heavy snowfall, ocean acidification and species extinctions due to shifting temperature regimes. Possible societal responses to global warming include mitigation by emissions reduction, adaptation to its effects, building systems resilient to its effects, and possible future climate engineering. Most countries are parties to the United Nations Framework Convention on Climate Change (UNFCCC) whose ultimate objective is to prevent dangerous anthropogenic climate change [4]. Currently, 90% of the total primary energy sources in the world are fossil fuels, and more than 85% in the USA (DOE, 2010). The use of fossil fuels is intimately linked to the emission of CO_2 into the atmosphere. The USA releases 1.59 GtC/yr and China 1.78 GtC/yr – 2007 data (CDIAC, 2009). Power plants account for ~40% of total CO_2 emissions. Once released into the atmosphere, CO_2 enters into the global carbon cycle and interacts with the ocean and terrestrial sinks. The estimated net annual increase of CO_2 concentration in the atmosphere is problematic since CO_2 is a greenhouse gas. The mean surface temperature has increased ~0.6±0.2 °C since the industrial revolution, and atmospheric models forecast as much as a ~3 °C increase by 2100 if anthropogenic CO_2 emissions continue current trends. Several technologies have been proposed for mitigating the emission of CO_2 into the atmosphere. Two clear options call for reducing the combustion of fossil fuels, and capturing the generated CO_2 followed by permanent sequestration. Suggested minimum storage time for CO_2 geological storage ranges between 1,000 and 10,000 years [5].

In this study an exploratory analysis was performed on CO_2 gas emissions and temperature changes off all countries in the world over the years of 1850 to 2012 to find meaningful patterns and discussions on the direct or indirect effect of CO_2 emissions on climate change. One hypothesis is that although many countries have a

low impact on climate change (CO_2 emissions), they are still dealing with drastic changes in temperature and climate affecting all aspects of life in their countries. The trend of cumulative CO_2 emission throughout the last century presents interesting facts about industrial growth in countries in historic periods like Britain Empire and the arms age of World War I and II.

3 Data

3.1 Data Acquisition

The data is a comprised of a set of CO_2 accumulative production data of all countries gathered since 1850 up to 2017 and a set of monthly temperature readings for 1843 to 2012. So, the common years that both data sets were sharing, from 1850 to 2012, were chosen and used in this study. The data sets were acquired from http://www.globalcarbonatlas.org [6] and http://berkeleyearth.org/data/ [7].

3.2 Data Preparation

The data at hand was relatively easy to work with and was almost already cleaned for our purpose. However, change of temperature is the main focus in this study not the temperature itself. The temperature data set is cleaned to get the annual change in temperature for every country. Also, the temperature is given for 12 months a year, and it was averaged over the months for each year. The greatest challenge was to find a meaningful reference point to calculate the change in temperature for every country. The reference point was chosen based on the available temperatures of each country and not the average global temperatures as the purpose is to compare changes in temperature for each country. This reference point was set to be 1850 since before that data is available only for a limited number of countries. The cumulative CO_2 production of USA has been the highest of all countries since 1910s. Today it counts for one third of the total cumulative CO_2 production.

4 Method

The flowchart in figure 1 displays the process used for exploratory analysis of the data sets related to CO_2 and temperature changes. This is followed by a prediction model to estimate CO_2 production and temperature changes over the next 50 years. Finally, the relationship between accumulative CO_2 and temperature changes are established.

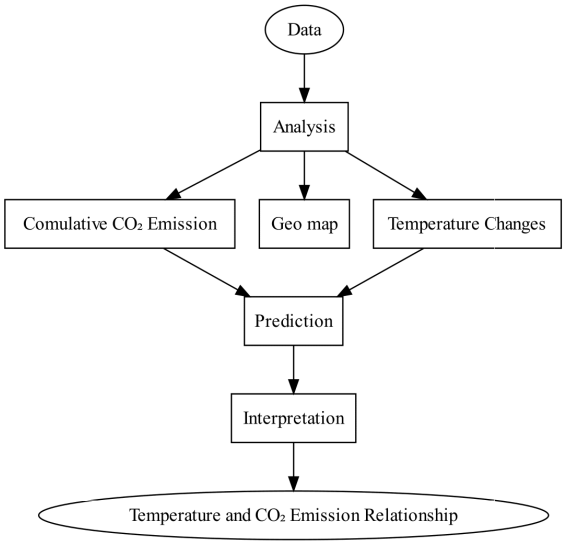

Figure 1: Flowchart of study proceedings

5 Data Analysis, Visualization and Discussion

In order to observe the share of each country in the accumulative CO_2 production through the last one and a half century, an interactive geomap of cumulative CO_2 emission around the world was produced using the "Shiny" application. The interactive geomap is provided in the presentation file [8].

It is evident from the graph that England produced the highest CO_2 on the planet up to 1890s. Afterwards, the USA became number one and has remained so to the present day. China has developed immensely throughout the last few decades and is currently the runner up in CO_2 emissions. The interactive geomap of temperature changes (ΔT being the difference from a reference temperature which has been set equal to the temperature of each country in 1850), is directly illustrating the effect of climate change in the past century. Every 50 years, there is clear increase of 1 degree Celsius in the maximum ΔT of many countries. Visually, the number of countries exhibiting these changes have increased since the start of the 21^{st} century.

The global temperature changes versus cumulative emitted CO_2 is displayed in figure 2. Each point of this figure represents the average CO_2 emitted versus the average temperature change with respect to the reference year (1850) for all countries in a single year. As CO_2 emission increases so does the global temperature. Based on Solomon et al. [3], CO_2 emission is directly affecting climate and temperature changes which is clearly visible in figure 2. To validate a direct relationship between CO_2 emission and global temperature changes, a correlation test was carried out to examine the association between these 2 paired samples. The resulted p-value approaching 0 indicates that CO_2 and temperature changes have statistically significant relationship. This value further justifies the objective of this study.

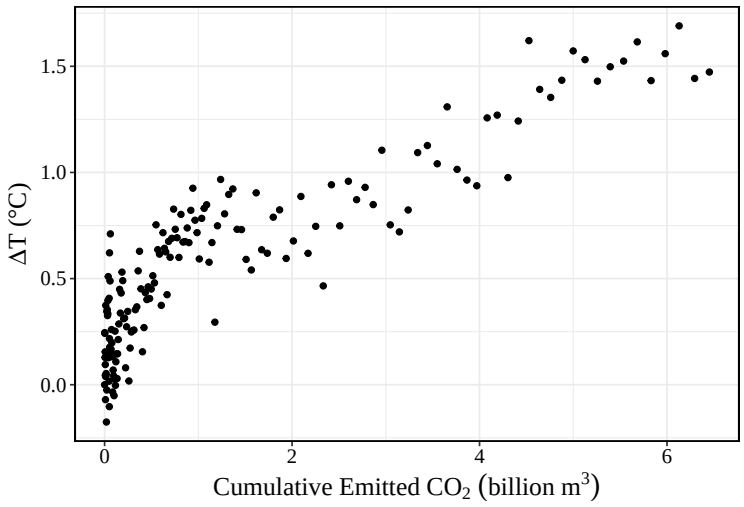

Figure 2: The correlation between temperature changes and CO_2 emission around the world

Table 1 presents top 10 countries with the highest cumulative CO_2 production up to 2012. These 10 countries are responsible for more than 71% of CO_2 production. United States and China with 27.3% and 11.1% account for more than one third of global CO_2 production. United Kingdom which used to be the top producing CO_2 country until 1890s is currently in the 5^{th} place with Russia and Germany at 3^{rd} and 4^{th} places. The United States' share is drastically higher than other countries while most Americans are oblivious to this fact.

Table 1: Top 10 CO_2 producing countries in the world up to 2012

Country	Cumulative Emitted CO_2 (billion m^3)	Contribution in CO_2 Production (%)
United States	372.00	27.62
China	151.00	11.21
Russia	92.22	6.85
Germany	86.54	6.43
United Kingdom	74.95	5.56
Japan	56.09	4.16
India	37.23	2.76
France	36.00	2.67
Canada	29.08	2.16
Poland	25.26	1.88

Figure 3 is the bar chart presentation of the top 10 CO_2 producing countries in the world. America's population only accounts for 4.3% of world's population while apparent from figure 3, America's share of CO_2 production up to 2012 is 28% of global accumulative CO_2 production. China in 2^{nd} position has produced less than half of America, mostly as a result of the late bloom of China's industry. It should also be noted that the amount of CO_2 that the United States produces is almost equal to the amount that all other countries that are not in this figure produce combined.

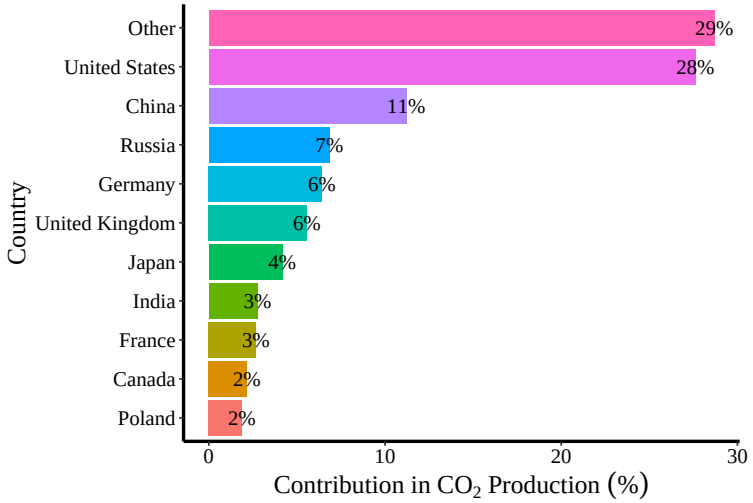

Figure 3: Bar Chart display of top 10 CO_2 producing countires and the rest of the world up to 2012

The line graph of CO_2 emission versus time displays the trend and jumps in CO_2 production of the top 5 countries. The sudden increase in CO_2 production of USA and China in 1890s and 1960s as a result of industrial growth is clear in the graph (figure 4). The rest of the leading countries have had a steady increase in CO_2 production throughout this period of time. The rate of China's CO_2 production suggests that in the near future China will become the number one CO_2 producing country in the world. A prediction model is thus used to observe this trend.

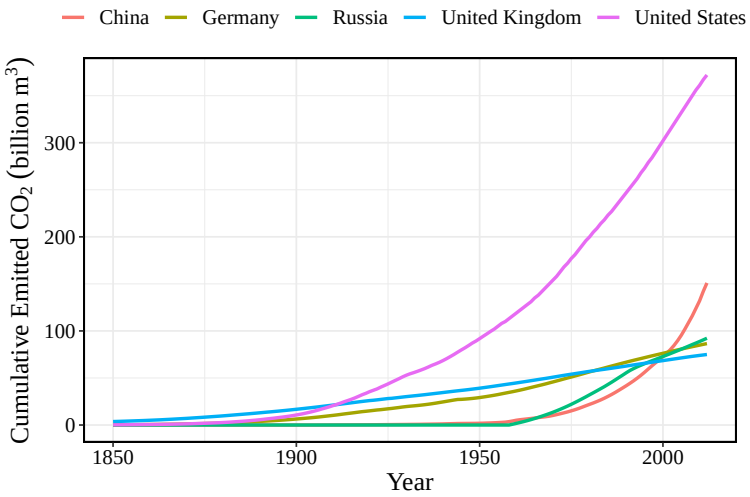

Figure 4: Cumulative emission of CO_2 versus time from 1850 to 2012

Temperature changes of the top 5 CO_2 producing countries (USA, China, Russia, Germany and UK) are displayed in figure 5 from 1850 to 2012. The general trend shows an increase in overall temperatures in all of these countries.

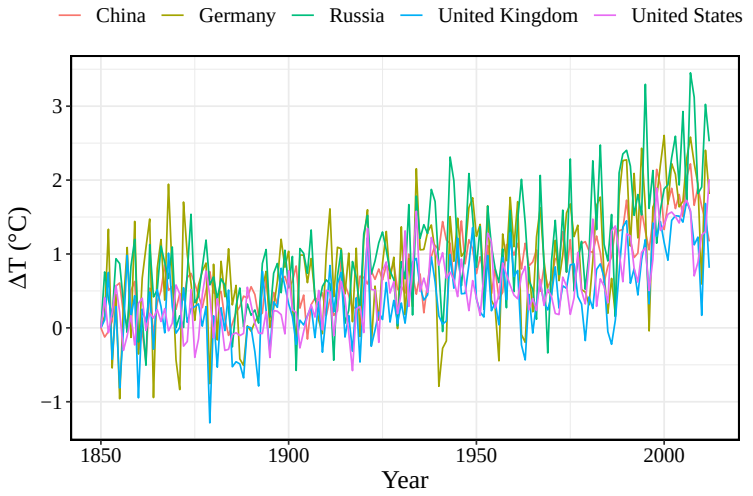

Figure 5: Changes in temperature versus of top 5 CO_2 producing countires from 1850 to 2012

The same can be concluded from the individual display of temperature changes over this period of time (figure 6). Figure 6 has the same information as figure 5, but all countries have been separated to make it easier to see the trend of each. However, the observation is still the increase in temperature for all of them.

The monthly temperature changes in USA and China displayed in figure 7 shows an increase through out this period. For these two countries, it seems that the increase is more notable for some months compared to others. Since this is out of the scope of this study, there should be a future work on this matter to see what causes different months to be affected differently.

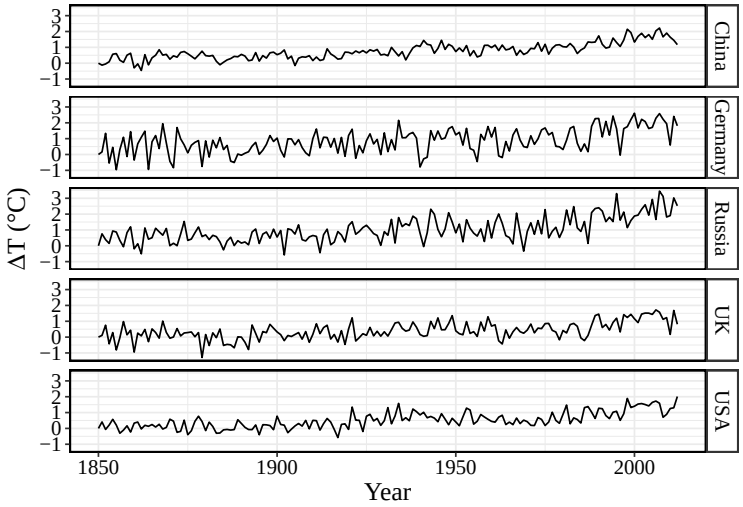

Figure 6: Facet display of temperature changes versus time of top 5 CO_2 producing countires

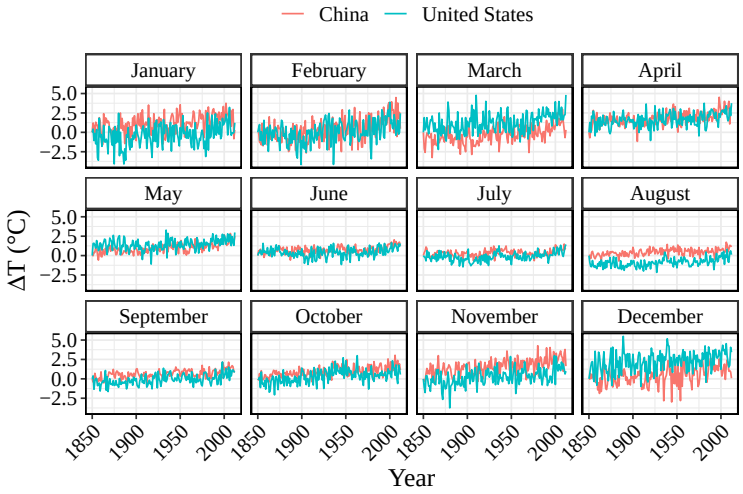

Figure 7: Monthly temperature changes of China and USA since 1850 to 2012

Bar chart of figure 8 is similar to the graph that was shown previously for CO_2 emission (figure 3), but here, temperature change is of interest. It shows the rank of those countries in temperature increase since 1850. It is interesting that two of the countries are located in the South America (Argentina and Chile) and most of them are located either in the middle east or very close to that area (e.g. Armenia, Azerbaijan, Qatar, Bahrain and Iraq). These are the top 10 countries in the world that had most changes in their average annual temperature compared to 1850. It shows that since 1850, a country like Argentina has become almost 4 °C warmer which can have a huge effect on this country.

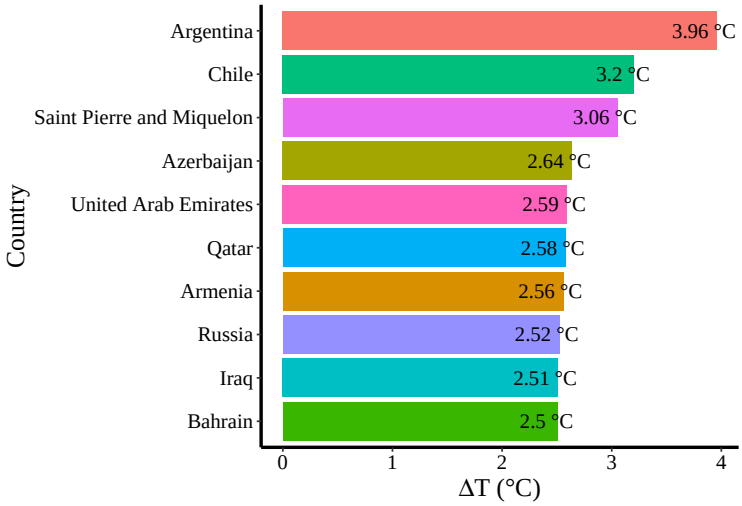

Figure 8: Top 10 countries with highest changes in temperature up to 2012

Table 2 shows the CO_2 producing rank of the top 10 countries with highest temperature changes. Out of all the top 10 CO_2 producing countries, only Russia is in this ranking proving that countries that produce the highest amount of CO_2 are not the ones affected the most, and climate change is a global matter and everyone from every country must be aware.

Table 2: Top 10 countries with highest changes in temperature up to 2012 and their corresponding CO_2 producing rank

Country	ΔT (°C)	Rank in CO_2 emission
Argentina	3.96	28
Chile	3.20	55
Saint Pierre and Miquelon	3.06	198
Azerbaijan	2.64	54
United Arab Emirates	2.59	46
Qatar	2.58	69
Armenia	2.56	105
Russia	2.52	3
Iraq	2.51	45
Bahrain	2.50	83

ARIMA, standing for 'Auto Regressive Integrated Moving Average', is a prediction algorithm that uses current data alone to predict future values. An ARIMA model is characterized by 3 terms: p, d, q. Where, p is the order of the Auto Regressive (AR) term, q is the order of the Moving Average (MA) term and d is the number of differencing required to make the time series stationary. For our purposes in R, an Auto ARIMA function was used that estimates p, d and q to best fit our data.

The best fit option was used in Auto Arima model on the top 5 CO_2 producing countries to predict their behavior in the next 50 years. From figure 9 and based on this forecast, China will exceed the Unites States in producing CO_2 in 31 years (solid lines representing the available data while the dashed ones are the predicted part). In reality based on these results, China and USA are responsible for CO_2 emissions in the future as well as its impact on the environment, climate change and our lives.

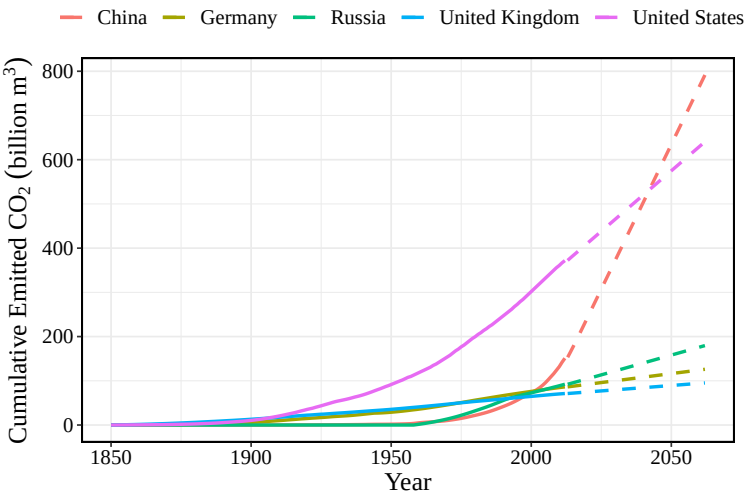

Figure 9: Comulative CO_2 emission of top 5 countires versus time from 1850 to 2012 including forecast data until 2062

Figures 10 to 14 show the forecast of temperature changes of the top 5 countries that produce the most CO_2 among others over the course of the next 50 years. There are also two grey areas where the ligther one represents the area for an 95% prediction interval while the dark one is for an 80% prediction interval (Solid lines are the available data while dashed lines represent the forecased data). Surprisingly, altough the United states is by far the top contributor to the CO_2 production, and based on figure 9 will remain on top at least for another 30 years, its temperature does not seem to change a lot over the next few decades.

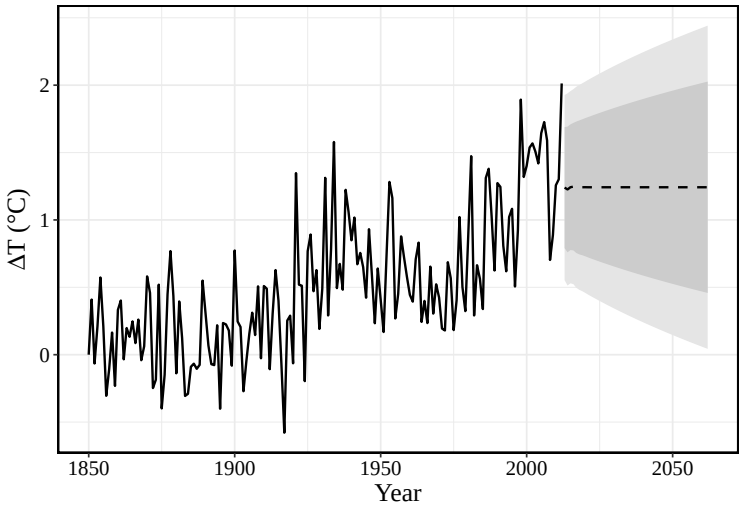

Figure 10: Prediction of temperature changes over the next 50 years - United States

Unlike the United States, for other top contributors namely China, Germany, United Kingdom and Russia, the story is different. Acording to figures 11 to 14, all of them show this gradual increase in their temperature change over the next half century. While all increasing, China seems to have the sharpest slope in the temperature change. Based on the forecast, the temperature will keep rising in the next 50 years if it is not addressed properly and promptly.

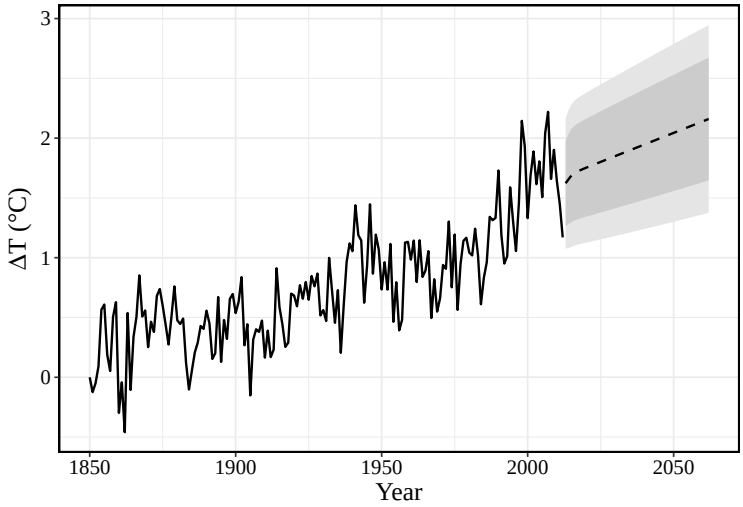

Figure 11: Prediction of temperature changes over the next 50 years - China

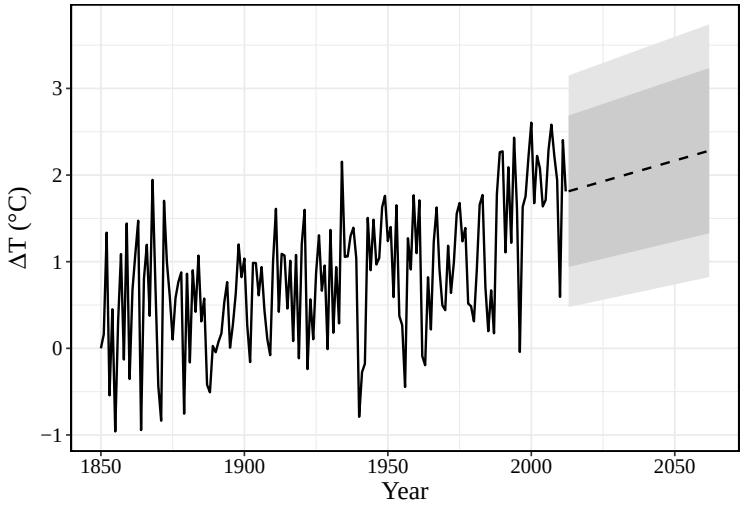

Figure 12: Prediction of temperature changes over the next 50 years - Germany

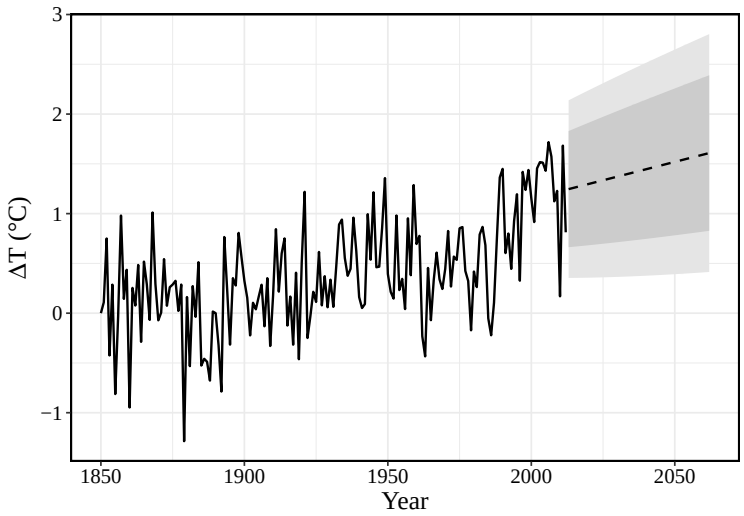

Figure 13: Prediction of temperature changes over the next 50 years - United Kingdom

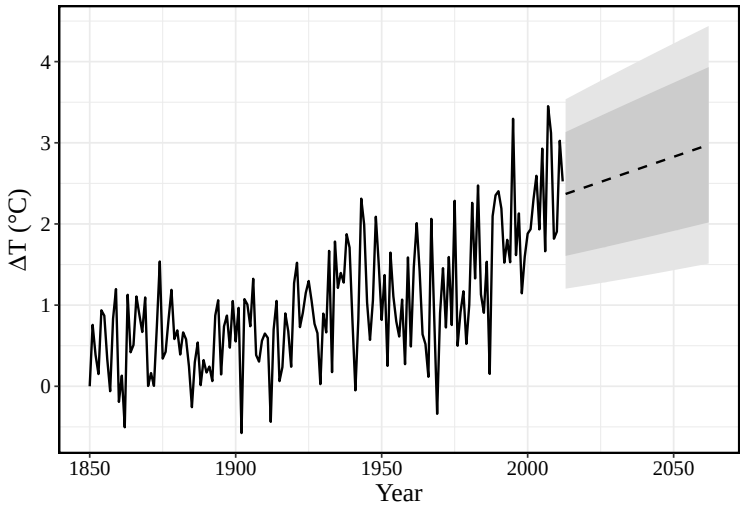

Figure 14: Prediction of temperature changes over the next 50 years - Russia

6 Conclusion

Cumulative CO_2 emission and temperature changes of all countries on the planet from 1850 to 2012 were studied to find the relationship between the two. Correlation test between CO_2 and temperature changes showed a P-value approaching zero which indicates a statistically significant relationship between the two. Results show that the top 5 CO_2 producing countries are USA (28%), China (11%), Russia (7%), Germany (6%) and United Kingdom (5%). However, Russia is the only country out of these 5 that can be seen in the top countries with highest temperature changes. Moreover, one of the countries that has experienced significant temperature increase is Saint Pierre and Miquelon while compared to most of the countries, the amount of CO_2 it produces is negligible (rank 185 out of 208 countries in CO_2 production). Thus, CO_2 emission and climate change are global issues and affect all countries no matter the location or their share in CO_2 production.

Considering the predict model provided, China will become the #1 CO_2 producing country in about 31 years. Also, the forecast shows that the temperature increase may not be an issue for the United States since the

Arima model shows a steady line with almost no increase. However, for other top CO_2 producing countries, an increase is anticipated.

Since the top CO_2 producing countries have not yet been drastically affected by climate change to this date (except for Russia), there is a lack of concern in this topic among the leaders of these countries. As climate change is considered irreversible by many researchers in this field [3], action must be taken today to safeguard the environment and the human race in the near future.

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