Proceedings of the 2023 International Conference on Environmental Geoscience and Earth Ecology
DOI: 10.54254/2753-8818/7/20230123

Analysis of the impacts of carbon dioxide emission on climate change

Yuyang Jiao

St John's College, Durham University, Durham, DH1 3RJ, UK

yuyang.jiao@durham.ac.uk

Abstract. In recent years, the global excess carbon dioxide emission had caused severe climate change and increase in global temperature since the start of Industrial Revolution. To be specific, extreme weathers have been observed all over the world due to global warming. Therefore, it is of vital importance that the causes of excess carbon dioxide emission should be studied along with respective mitigating strategies. On this basis, this study aims to study and investigate the global history and causes of excess carbon dioxide emission, as well as the physical chemical mechanism of greenhouse effect. In detail, case analysis of excess carbon dioxide emission in China is provided with the relevant negative impact of climate change in China. According to the analysis, policies adopted by the Chinese government and their efficiencies and corresponding suggestions are also discussed in the meantime. Overall, these results shed light on guiding further exploration of carbon dioxide emission on climate change.

Keywords: carbon dioxide emission, greenhouse effect, global warming, climate change in China, relevant policies in China.

1. Introduction

Climate change is a modern major global concern which has already caused multiple negative impacts on different world regions, such as regional flooding, dry-season rainfall reductions and irreversible rise in ocean temperature which causes catastrophic damage on marine ecosystem. Carbon dioxide, fluorocarbons, nitrous oxide, and methane are four major types of Human-caused Greenhouse Gas (GHG). The cumulating and increasing emission of GHG predominantly leads to current adverse climate change. The cumulative compositions of these greenhouse gases from year 1990 to year 2019 can be seen in Figure 1. It is evident that the emission of carbon dioxide is the most concerning factor which takes up the largest percentage of total greenhouse emission with increasing rate. The emission of carbon dioxide takes up about 80% of total greenhouse emission. The increasing trend of global carbon dioxide emission from year 1850 to 2021 can be seen in Figure 2. It can be observed that the rate of carbon dioxide emission has been rapidly increasing since year 1946. This is caused by the rise in the number of countries taking part in industrial development.

Up until year 2022, the global carbon dioxide emission achieved the highest level in the past two million years [1]. In 2022, the carbon dioxide concentration increased by around 2.1 ppm relative to year 2021 and methane increased by around 12 ppb relative to year 2021. This leads to an approximated result of average 417 ppm for carbon dioxide emission and 1894 ppb for methane emission. Carbon dioxide is emitted by natural carbon cycle such as respiration of animals, as well as emitted through

DOI: 10.54254/2753-8818/7/20230123

other human activities such as the burning of fossil fuels in heat engines. At previous equilibrium state, the emitted carbon dioxide in the atmosphere is then reduced by the plant respiration process and absorbed by the oceans. However, the rate of carbon dioxide emission had been increasing since 1700s and further accelerated since the start of Industrial Revolution in the 1830s. With more developed and developing countries taking part in manufacturing and enhancing their heat engines, in the 21st century, the world has witnessed the significant increase in carbon dioxide emission on a global scale along with the subsequent negative impacts on climate change.

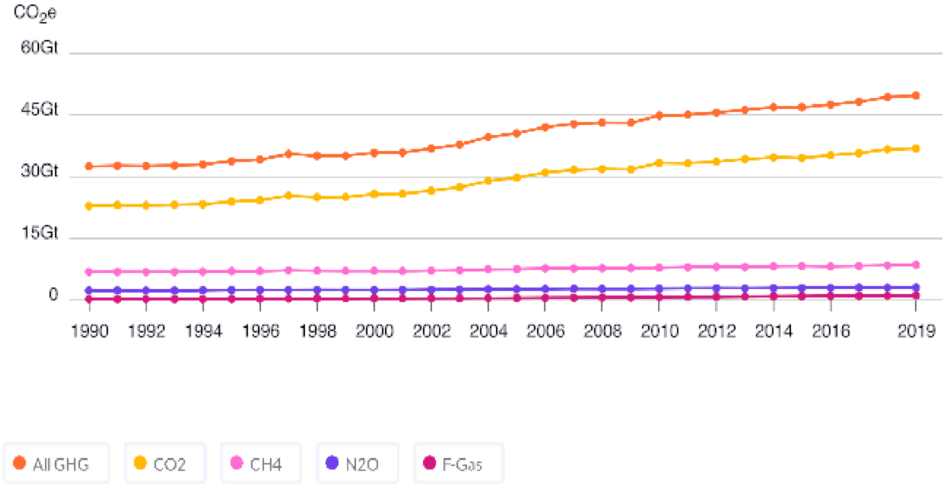

Figure 1. Historical records of four major types of greenhouse emissions from 1990 to 2019 (Photo/Picture credit: Climate Watch).

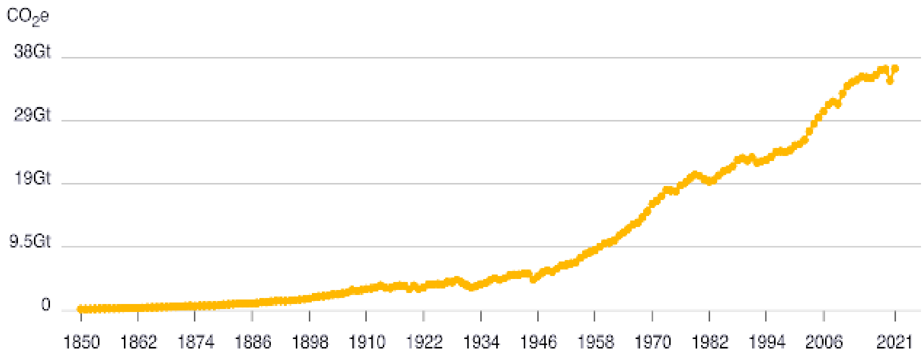

Figure 2. Historical records of carbon dioxide emission from 1850 to 2021 (Photo/Picture credit: Climate Watch).

The study of relationship between carbon dioxide concentration and global warming effect has been a major topic for many fields of science as it is vital for future survival of humanity. Researchers present an analysis of the relationship between climate change and severe climate conditions [2-4]. The authors argue that the observed increase in extreme weathers, such as heatwaves and floods, is largely due to human-caused climate change. The paper highlights the need for urgent action to reduce greenhouse gas emissions to avoid further increases in extreme weather events.

Other scholars argue that the cumulative amount of carbon dioxide emissions is a better predictor of future warming than the annual emissions rate. The authors estimate that a cumulative total of 500 billion tons of carbon dioxide emissions will lead to an increase in global temperatures by 1.5 °C compared to the levels before industrialization, which is considered a safe threshold. The paper highlights the need for urgent action to reduce carbon dioxide emissions to avoid dangerous levels of warming. The main conclusions of the IPCC's Fifth Assessment Report are outlined in this document. It underlines the compelling proof that human actions, particularly the combustion of non-renewable energy sources, are

DOI: 10.54254/2753-8818/7/20230123

the main cause of climate change. The report emphasizes the necessity of taking immediate measures to decrease greenhouse gas emissions in order to prevent hazardous levels of temperature rise.

China has become the world's largest emitter of carbon dioxide as observed from Figure 3. This leads to a significant environmental concern. China is a fast-developing country with vast lands and great populations. The survival of China depends heavily on both industrial and agricultural development. China has emerged as one of the world's largest manufacturers as well as importers of steel, cement, and other industrial goods, which requires large amount of energy and emits a significant amount of carbon dioxide. Coal remains the primary source of energy in China, account for over 60% of the country's energy consumption. China is also home to some of the world's largest coal-fired power plants. The tremendous amount of carbon dioxide emission in China has brought severe air pollution and extreme weather to the nation, which threat the health of people living in polluted area and negatively impact the agriculture development of China, thus endangering the economic growth and people's standard of living.

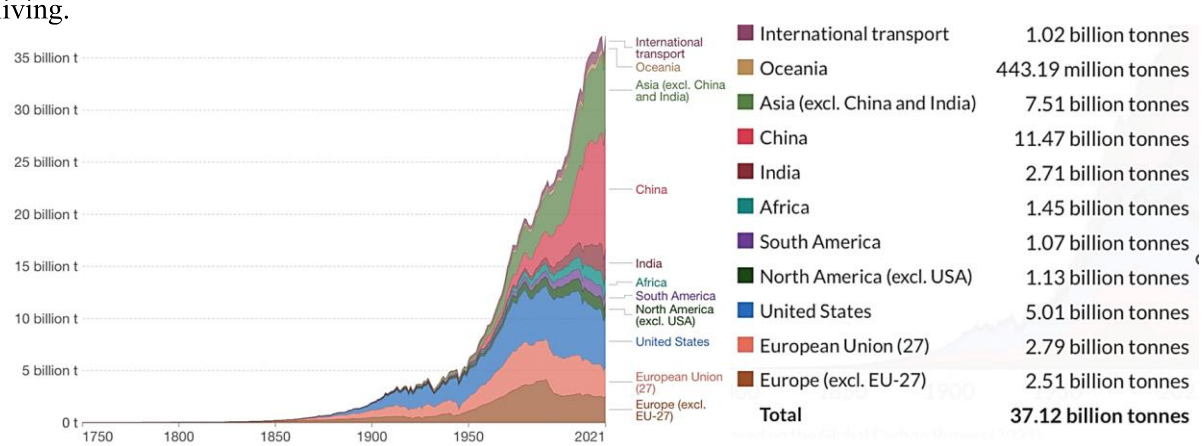

Figure 3. Annual carbon dioxide emission from 1750 to 2021, sorted by world regions with a table on the right showing specific amount contributed by different countries in 2021 (Photo/Picture credit: Our World in Data based on the Global Carbon Project 2023).

2. Physical principles of greenhouse effect

A simple description would be molecules of carbon dioxide in the atmosphere trap a portion of infrared radiation which is otherwise radiated out into the space. More detailed explanation of the mechanism requires knowledge of chemistry and physics. Infrared radiations carry most heat energy of the magnetic waves (i.e., the light) emitted by the Sun and they travel with wavelengths ranging from 700 to 1000000 nanometres. Therefore, infrared waves do not interact with oxygen and nitrogen molecules, because these molecules only absorb energy from wavelengths of about 200 nanometres or less, whereas greenhouse gases like carbon dioxide can absorb energy at a greater variety of wavelength from 2000 to 15000 nanometres, which overlaps with the range of infrared wavelengths.

The reason of carbon dioxide molecules' ability to absorb a wider range of wavelength is that they are made up of three atoms, which enabling them to stretch, bend and twist in more different ways, in contrast with limited interactions of oxygen and nitrogen molecules, which only contain two atoms. This is called the presence of different electronic dipole moments in various gas molecules. Within a molecule, there are two distinct groups of charged particles: the positively charged protons from its atoms and the negatively charged electrons. Each of these groups has a centre of mass, or barycentre, and if the barycentre does not align, the molecule has an electric dipole moment. However, symmetrical diatomic molecules like N_2 and O_2, which are abundant in the atmosphere, have barycentre that overlap, resulting in a zero electric dipole moment. Consequently, these molecules do not significantly engage in energy exchanges with photons.

On the contrary, molecules with higher intricacy, such as CO_2, H_2O and CH_4 contain vibrational modes that aid in energy absorption. CO_2, for example, is a linear and symmetrical molecule with two double bonds arranged as O=C=O. Consequently, the O atoms can vibrate to capture energy, either by bending on either side of the average position or by moving symmetrically away from or towards the C atom [5].

Quantum character of the photon plays an important role in energy absorption and transmission in the atmosphere and thus explaining the greenhouse effect [6]. Specifically, the photon's energy must match the energy gap of the molecule's vibrational mode. As a result, molecules are capable of absorbing only specific wavelengths. Consequently, certain molecules can absorb the Earth's infrared radiation within bands of precise wavelengths, known as absorption windows, which are separated by transparent bands. Molecules in the atmosphere that have absorbed a portion of the Earth's infrared radiation transfer it to neighbouring molecules through collisions. This process causes a certain amount of heating of the gaseous medium, which in turn contributes to the distribution of temperature. Additionally, the atmosphere emits some of this energy to the land and oceans (150 W/m2), which is known as the greenhouse effect.

3. Irreversible impact of carbon dioxide emission

There are two irreversible negative impacts of carbon dioxide emission on climate change. In this context, the irreversible impact means that the changes in climate changes is largely impossible to offset for 1000 years after the emission ends. The first irreversible negative impact of carbon dioxide emission is the prolonged carbon dioxide perturbation in the atmosphere. Carbon dioxide takes up almost 80% of total greenhouse gases in the atmosphere and it is also the most persistent greenhouse gas. The removal of carbon dioxide in the atmosphere involves various complicated processes such as the fast rate exchange process between the atmosphere and the surface biosphere. By contrast, the absorption of carbon dioxide by the ocean is a larger scale but much slower process, involving chemical transitions between air and the interior of the ocean [7]. The efficiency of removal of carbon dioxide through biosphere and ocean is lowered by the additional carbon cycle feedbacks, prolonging the decay time of carbon dioxide in the atmosphere. Therefore, the excess carbon dioxide concentration is difficult to be offset.

The second irreversible impact on climate change is the atmospheric warming effect caused by the presence of carbon dioxide, leading to further changes in precipitation and the rise in sea level. The current excess amount of carbon dioxide presenting in the atmosphere making it less transparent to the infrared radiation, which is emitted by the earth surface. The emission of infrared radiation from the earth to the atmosphere and then further emitted by the atmosphere into the space is a main process of reducing excess heat energy of the globe. However, the trapped infrared radiation is now partially emitted back to the Earth surface, heating up the Earth surface and the near atmosphere. From the well-known Clausius-Clapeyron law [8], the increase in surface temperature leads to an increased saturated water vapor concentration in the atmosphere. This leads to a change in precipitation rate and the total rainfall [9]. There has been an observed decrease in long-term rainfall in regions of Southern Africa, Mediterranean and south-western North America [10]. The subsequent long-term dry seasons bring severe impact on the availability of daily water supply for normal human activities as well as the development of agriculture and the protection of ecosystem. The rise in sea level is also caused by the greenhouse warming effect due to the thermal expansion of ocean. Moreover, the increase in volume of melted land ice and melted Antarctic ice sheets makes significant contribution to the rise in sea level [11].

4. Methods of measuring regional carbon dioxide emission

The current technology has been adopting the following four-step-method of measuring regional carbon dioxide emission [12]. The first step is to gather the data on the amount of total domestic industrial production of extracted coal, brown coal, peat and crude oil. This amount of coal extraction provides the expected value of energy produced by the region, if all the extracted coal is used domestically. The second step is to account for fossil fuels imported and exported by the region as well as the number of fuels that the local government decides to store as stocks. The estimated amount of burnt coals in the region = Coal imported+ Coal extracted - (Coal exported + Coal stored as stocks). The third step is to calculate the amount of regional carbon dioxide emission from using the amount of burnt coal estimated in the second step. The emission factor is the amount of carbon dioxide emitted by every kilogram of burnt coals. The total carbon content is calculated by multiplying the emission factor by the quantity of burnt coal. The first three steps finish the calculation of the emission of carbon dioxide from the burning of coals. The last step is to repeat the same calculation for all types of fuel in the region, thus sum all the results together to obtain the total regional carbon dioxide emission.

5. Case analysis of China

China accounts for 30% of global carbon dioxide emission [13], and just like most of the primary carbon dioxide emitters, most of the carbon dioxide emission is caused by the combustion of fossil fuels in industrial plants. The annual carbon dioxide emission of China is calculated as a combination of four factors, namely carbon intensity (CI), energy intensity (EI), per capita gross domestic product (PCG) and population size (P). The weighted contributions of these four factors to carbon dioxide emission are indicated by the index decomposition analysis (IDA) [14]. Equation (1) shows the calculation of carbon dioxide emission in China using the four factors:

$$CO_2 = \frac{CO_2}{E} \cdot \frac{E}{GDP} \cdot \frac{GDP}{P} \cdot P = CI \cdot EI \cdot PCG \cdot P \tag{1}$$

Here, E is the primary energy consumption of China, GDP is the gross domestic product of China, P is the population size. Carbon intensity (CI) is the ratio of carbon dioxide emission to energy consumption. Energy intensity (EI) is the ratio of energy consumption to GDP. Per capita gross domestic product (PCG) is the ratio of GDP to population.

China is home to many diverse ecosystems due to her vast land area (960 Mha) and widespread latitude (from 18 to 53-degree North). Therefore, the vegetation in China is diverse, consisting of various ecosystems that range from tropical rainforests and evergreen broadleaf forests in the south to evergreen or deciduous coniferous forests in the north. The Great Eastern Plains, which comprise the middle and lower parts of the Yangtze River Basin, northern plains, and northeastern plains, host a variety of temperate vegetation. The Tibetan Plateau has cold grassland, meadow, and cushion vegetation, and the western regions have the Mongolian steppe and Gobi Desert [15]. Geographical differences in the carbon cycles can be analysed in China due to her wide range of ecosystem diversity. Various impacts of climate changes as well as policy shifts can also be analysed, along with the interactions between terrestrial systems and atmosphere.

China's sensitivity to global climate change is largely due to its monsoon climate. The past three decades have seen an increase in mean annual air temperature by over 1.0 °C, which is higher than the global average. Despite a lack of significant change in overall annual precipitation, there have been notable shifts in both regional and seasonal patterns throughout China. These alterations in climate have had a deep-seated effect on the structure and function of the country's ecosystems.

After year 2000, warming trends have been observed across 75% of the temperature monitoring stations in China [16] (as shown in figure 4a). Tibetan Plateau and Yunnan are areas with 17.5% stations which experience most concentrated and dominant warming trend. Now all areas of the nation experience warming. There are around 28.5% stations experience cooling, and they are mostly in the western and northeastern parts of the arid northwestern region as well as the eastern monsoon region. As for seasonal variation, differences in the temperature are more significant.

DOI: 10.54254/2753-8818/7/20230123

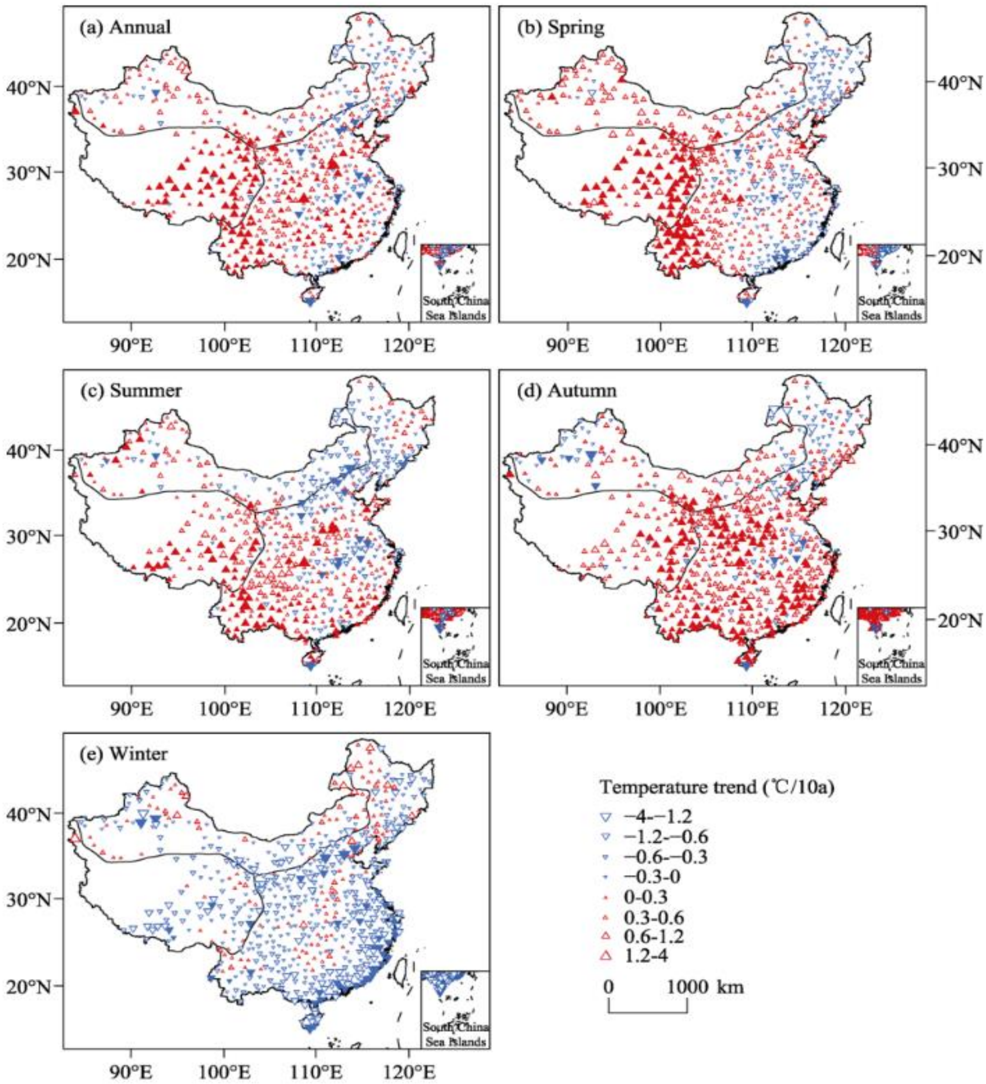

Figure 4. Average air temperatures in China over 2000-2016, recorded by temperature monitoring stations across China. (a) annual temperature; (b) spring temperature; (c) summer temperature; (d) autumn temperature; (e) winter temperature [13].

From observation in figure 4b-4e, warming trends occurs in spring, summer and autumn and the most dominant warming occurs during autumn in which central lands experience the most extreme rise in temperature, whereas the most dominant cooling occurs in winter and the southern areas along South China Sea experience most extreme decrease in temperature. Therefore, global warming does not bring only a holistic increase in temperature across all lands and all seasons, but it causes more extreme temperature changes in China. Winter becomes colder and summer becomes hotter. The extreme temperature variation leads to abnormal weathers in all seasons such as shifting of rain belt northwards across recent years, as well as worsening air pollution in many northern cities because of the lack of strength in northwest monsoon trapping polluted particles inside the regions.

In the summer of 2020, particularly in June and July, China's Yangtze River Valley (YRV) experienced periods of intense heavy rainfall, resulting in the most severe flooding in the region since 1998 [17]. Despite this, the 2020 western North Pacific (WNP) typhoon season had a slow start but eventually produced 23 named tropical cyclones, slightly below the seasonal average of 27. As the summer gave way to winter, three severe cold surges swept across most parts of China in late 2020 and

DOI: 10.54254/2753-8818/7/20230123

early 2021. This prompted the National Meteorological Centre to issue its highest cold surge warning alert for the first time in four years.

6. Policy and suggestions

The primary focus of mitigating the negative impact of climate change caused by excess carbon dioxide emission is to improve the efficiency of energy-intensive industries. China is currently giving high priority to energy conservation, energy saving, and emissions reduction in order to ultimately bring down CO_2 emissions. Additionally, China has implemented a more proactive policy aimed at promoting the progress of renewable energy, which will gradually hasten its development and enhance the energy structure. It is predicted that by 2030 and 2050, non-fossil fuel energy consumption will account for 20% and 50% of the total energy consumption, respectively [18]. Chinese government has made tremendous efforts in reducing carbon emission [19]. However, the excess emissions of carbon dioxide will still present for decades and strategies combating the potential negative impacts should also be discussed and prepared. China is a big nation, despite lowering per capita emission, the total carbon dioxide emission of the whole nation is still responsible for 30% of the world carbon emission. Therefore, to solve the root cause of excess carbon emission, it is vital that China prioritize on finding renewable energy resources and increase the investment in research institutions. To enhance the energy structure, offering robust economic incentives for switching from fossil fuels to renewable energy sources can stimulate the substitution of fossil fuels with non-fossil fuel options. It is essential to swiftly decrease coal consumption by imposing a cap on coal consumption and creating clean coal technologies such as coal cleaning and carbon capture and storage. Furthermore, to expedite the advancement of non-fossil fuel energy sources, especially renewables, it is vital to promote eco-friendly and low-carbon consumption behaviour through policy interventions [20].

7. Limitations and prospects

There are two sources of doubt when it comes to measuring carbon dioxide emissions. The first one pertains to the reporting of energy consumption, which is closely linked to economic and trade data that are typically monitored closely. As a result, energy reporting has low levels of uncertainty. However, countries' assumptions about the current carbon dioxide emission factor for specific types of fuels can lead to greater uncertainty. The level of uncertainty in these calculations can vary depending on the size of the country and can significantly impact the accuracy of global emission figures. Previous study discovered that China overestimated its annual emissions in 2013 by using global average emission factors instead of specific figures for the carbon content of its domestic coal supply. This error had a significant impact on global emissions estimates, resulting in a 10% overestimation. Generally, uncertainty around global carbon dioxide emissions ranges from 2% to 5%.

The prospects of climate change are intricate and uncertain. Based on climate models, it is anticipated that if greenhouse gas emissions persist at current levels, global temperatures will continue to increase, leading to more frequent and intense heatwaves, droughts, floods, and storms. This will result in rising sea levels, loss of biodiversity, and scarcities of food and water, which will adversely impact human health, economies, and security. Nevertheless, by taking strong and immediate action to reduce greenhouse gas emissions, the worst consequences of climate change can be prevented. The Paris Agreement, endorsed by nearly all countries worldwide, strives to restrict global warming to below 2 degrees Celsius above pre-industrial levels, with an objective of limiting warming to 1.5 degrees Celsius. To achieve this, countries must significantly intensify their efforts to decrease emissions and shift to a low-carbon economy. The prospects of climate change depend extensively on the actions one undertakes today.

8. Conclusion

In summary, the mechanism of excess carbon dioxide emission causing global warming has been studied and detailed analysis of climate changes in China has been presented. Policies of reducing carbon dioxide emissions adopted by China as well as many countries have been proven to be useful but still not sufficient. Despite being the major carbon dioxide emitter, China has been taking proactive measures to improve efficiencies in industrial production sectors as well as promoting technology innovations in developing renewable energy sources. Climate change is a global concern which requires every country to acknowledge the danger of global warming and devote resources into decreasing carbon dioxide emission. Our futures chance of survival and standards of living depend on our current effort and determination in combating climate change. This report serves as an in-depth discussion of the relationship between excess carbon dioxide emission and climate change, thus inspiring more scientists to enhance current policies adopted to contribute to the betterment of the earth.

References

[1] T. M. Gür, Prog. in *Ener. & Comb. Sci*. 89, 100965 (2022).
[2] Rahmstorf, S., & Coumou, D. Increase of extreme events in a warming world. Proceedings of the National Academy of Sciences, 108(44), 17905-17909 (2011)
[3] Knutti, R., & Rogelj, J. The legacy of cumulative carbon emissions. *Nature Climate Change*, 8(7), 563-568 (2018).
[4] Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *IPCC*. (2014).
[5] S. Fecht, How Exactly Does Carbon Dioxide Cause Global Warming. Columbia Climate School. *https://lamont. columbia. edu/news/how-exactly-does-carbon-dioxide-cause-global-warming* (accessed on 25 February 2021).
[6] René MOREAU, Overview of the physics of the atmospheric greenhouse effect, *Encyclopedia of the Environment, Earth's Atmosphere and Gaseous Envelope*.
[7] Revelle, HE Suess, Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO2 during the past decades. *Tellus* 9, 18–27 (1957).
[8] J. M. Wallace, P. V. Hobbs, Atmospheric science: an introductory survey (Vol. 92) (Elsevier London, 2006).
[9] M. R. Allen, W. J. Ingram, *Nature* 419, 224–232 (2002).
[10] E. J. Burke, S. J. Brown, N. Christidis, J Hyd. 7, 1113–1125 (2006).
[11] B. R. Parizek, R. B. Alley, *Quat Sci Rev* 23, 1013–1027 (2004).
[12] H. Ritchie, M. Roser, P. Rosado, CO_2 and Greenhouse Gas Emissions, Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-greenhouse-gas-emissions' [Online Resource] (2020).
[13] International Energy Agency, CO2 emissions from fuel combustion. https://westore.idea.org/co2-emissions-from-fuel-combustion-2018-highlights, (2018).
[14] K. Fang, S. J. Davis, L. Sun, K. Hubacek, Nay. Commun. 6, 7714 (2015).
[15] J. Y. Fang, *Ecography* 35, 1059–1071 (2012).
[16] Q. Du, M. Zhang, S. Wang, C. Che, R. Ma, Z. Ma, Col. of Geo. and Env. Sci., 1, 730070, China (2019).
[17] Chinese Academy of Sciences, Causes of Extreme Weather and Climate Events in China During 2020/21, PHYS.ORG, (28th April 2021).
[18] National Development and Reform Commission, The energy production and consumption revolution strategy (2016-2030).
[19] X. Zheng, Y. Lu, J. Yuan, et al., Roy. Swe. Aca. of Sci., Stockholm, Sweden (2019).
[20] Q. Liu, Adv. Clim. Chang. Res. 9, 27–33 (2018).