The Impacts Of COVID-19 Pandemic on Greenhouse Gas Emissions and Climate Change

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Abstract. The outbreak of COVID-19 in 2020 has brought enormous damage to human life and health and socioeconomic development. Yet, the influence of COVID-19 outbreak on the environment within the context of global warming has not been fully understood. Detailed and accurate explanation for the relationship between COVID-19 and economy, carbon emissions, and methane emissions remains a challenge. This study aims to highlight the significant impact of the COVID-19 pandemic on greenhouse gas emissions and climate change through a systematic literature review and comprehensive analysis of data from the U.S., China, Canada, and 27 European countries. To clarify the impact of COVID-19 on climate, the study outlines changes in carbon dioxide emissions by comparing data from pre-pandemic, during-pandemic, and post-pandemic (projected) scenarios. The correlation among carbon dioxide, temperature, GDP, and Population in countries is further examined with different levels of development using Pearson's Linear Correlation analysis and significance test. This study will potentially provide insights into future preparation and management of the impact of global emergency disaster emergencies.

Keywords: COVID-19 Pandemic, Climate, CO2 emission, Methane.

1. Introduction

In the last hundred years, the COVID-19 outbreak is the first major global environmental crisis indicative of a crisis distinct from war, recession, or disaster of any kind(Barouki，2021)(Lahcen, 2020). The sudden epidemic broke the balance in people's imagination and the idea of commodity economy in the traditional sense. Perhaps far from being a pandemic like the Spanish flu or the Black Death of Europe, the crisis will have a deeper and more lasting impact on economic, environmental, social and equality issues(Rodrigues，2021)(Mishra，2021). As one of the biggest epidemics in human history, COVID-19 patients present with symptoms ranging from the common cold to severe lung infections, posing a great threat to human life and property, so countries around the world want to take different measures to contain the spread of the novel coronavirus(Rodrigues，2021). In this pandemic crisis, different countries and regions have adopted different vaccination, economic stimulus, and social policies, with different consequences for greenhouse gas emissions and the climate (Wang, 2022).

It is worth noting that at the beginning of the COVID-19 outbreak, lockdown and quarantine policies were adopted by countries that brought key economic activities to a near halt. Many industries have been hit hard by massive lockdowns and work stoppages (Khan, 2021). For example, tourism, catering, retail and so on have suffered huge losses(Barouki，2021) . In addition, many companies went bankrupt because they could not function properly, leading to a lot of unemployment(Kapecki，2020). Although these industries have gradually recovered as the pandemic has been brought under control, there has been a lasting impact on the global economy (Kumar, 2022). The impact of COVID-19 on carbon emissions is also significant. Global carbon emissions have fallen during the pandemic because of reduced production (Bouman et al., 2020).

While COVID-19 has a considerable impact on greenhouse gas emissions in the short term, the influence of GHG on environment is still unclear. To date, several review articles have critically examined the impact of COVID-19 on parameters involved in environmental and climate change and policymaking for a clear analysis of COVID - 19, however, greenhouse gas emissions, economic growth, and environmental policy articles are still missing (Barouki et al., 2021) (Aktar et al., 2021)

(Bouman, Thijs, 2020) (Wetzels and Eric-Jan, 2012) (Lahcen, 2020). Firm environmental and energy-related policies related to post-COVID-19 economic recovery can only be helped when the long-term environmental impact of COVID-19 is understood and evidence gathered (Iqbal, 2020).

In this context, the underlying themes of this study are the impact of the COVID-19 on greenhouse gas emissions and climate change, as well as the relationship between carbon, methene, surface temperature, and GDP within the period of COVID-19. To further examine the potential relationships aforementiond, Pearson Linear Correlation was used to analyze the correlation between the data of four different representative countries or regions over the past decades and whether COVID-19 weakened the correlation between various factors (Kumar, 2022). The changes of greenhouse gas emissions before and after the epidemic were compared. The CO2 emissions of different production sectors under the influence of COVID-19 were analyzed. Finally, this paper puts forward some suggestions for global sustainable development. This study will potentially shed light on an early-warning system for policymakers and environmentalists to better modify environmental policies, develop sustainable development strategies, and improve disaster response capacity to deal with future major epidemics.

2. Data and Method

2.1. Data

This study collected the data from the United States, Canada, China, and the European Union at macrotrends; CO2 emission data were collected at OurWorld Data; Methane emissions data were collected at stats.oecd; Data on GDP and mean annual temperature were collected from the worldbank. Study and analyze the data collected. We us R studio to conduct a basic statistic calculation to get the Table 1. In table one We can see the Mean, Median, Standard Division, Quartile, and extreme value of Population, CO2, GDP, Temperature from 1980 to 2021 over four countries.

Table. 1 Statistic of Population, CO2, GDP, and Temperature over 4 countries from 1980 to 2021

China	Mean	Median	Standaerd Devision	Q1	Q3	Maximum	Minimum
Population (person)	1.23×109	1.26x10^{9}	1.3x108	1.13x10^{9}	1.34x109	1.43x109	9.18x109
CO2 (million tons)	4.41x109	3.68x109	3.33x10^{8}	2.48x10^{9}	9.59x109	1.15x1010	1.48x1010
GDP (Billions of US$)	1.57x1012	1.28x1012	5.06x1012	3.58x1011	7.80x1012	1.77x1013	1.91x1011
Temperature(°C)	7.42	7.48	0.44	7.08	7.79	8.19	8.19
US	Mean	Median	Standaerd Devision	Q1	Q3	Maximum	Minimum
Population (person)	2.80×10^{8}	2.84x10^{8}	3.58x107	2.47x108	3.15x10^{8}	3.37x10^{8}	2.23x10^{8}
CO2 (million tons)	5.34x109	5.37x109	4.87x10^{8}	5.04x10^{9}	5.76x109	6.14x109	4.43x109
GDP (Billions of US$)	9.47x1012	1.04x1013	5.82x1012	5.88x1012	1.58x1013	2.30x1013	2.86x1012
Temperature(°C)	9.31	9.36	0.52	8.91	9.66	10.62	8.32

Canada	Mean	Median	Standaerd Devision	Q1	Q3	Maximum	Minimum
Population (person)	4.08x107	3.09x107	4.01x10^{6}	1.13x107	3.44x107	3.82x107	2.45x107
CO2 (million tons)	5.13x10^{8}	5.44x10^{8}	6.13x107	4.58x108	5.70×108	5.94x108	4.05x108
GDP (Billions of US$)	8.36x1011	7.41x1011	5.55x1011	5.74x1011	1.57x1012	1.99x1012	2.74x1011
Temperature(°C)	-4.17	-4.38	0.73	-4.69	-3.67	-2.49	-5.97
Europe (EU27)	Mean	Median	Standaerd Devision	Q1	Q3	Maximum	Minimum
Population (person)	4.30x108	4.29x108	1.21x107	4.20x108	4.41x108	4.47x108	4.08x10^{8}
CO2 (million tons)	3.52x109	3.66x10^{9}	3.31x10^{8}	3.31x10^{9}	3.77x109	4.07x109	2.62x109
GDP (Billions of US$)	8.33x1012	8.19x1012	4.72×1012	6.17x1012	1.47x1013	1.71x1013	2.30x1012

2.2. Pearson's Linear Correlation and Significance Test

Correlation is used to test relationships between quantitative variables or categorical variables. In other words, it is a measure of how things are related. The study of how variables are correlated is called correlation analysis. The formula for estimating the correlation coefficient is as follows,

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{n}} \tag{1}$$

where r is the correlation of the linear relationship between the variables x and y. x and y are two arrays or time series, and n is the number of the samples. Additionally, 2 sample t test is used in the paper that is used to compare the means of two groups (Kumar, 2022). It is often used in hypothesis testing to determine whether a process or treatment actually has an effect on the population of interest, or whether two groups are different from one another (Kumar, 2022).

$$\mathrm{t} = \frac{(\bar{X}1 - \bar{X}2) - (\mu 1 - \mu 2)}{\sqrt{\frac{S1^2}{n1} + \frac{S2^2}{n2}}} \tag{2}$$

Where t is test statistic; X1 is the sample mean value of of variable1; X2 is the sample mean value of of variable2; u1 is the population mean value of of variable1; u2 is the population mean value of of variable2; S1 is the sample variance value of of variable1; S2 is the sample variance value of of variable2; n1 and n2 are the sample number of variable1 and variable2 (Wetzels and Eric-Jan, 2012).

3. Results and Discussion

3.1. COVID-19's impact on GHG emission

Fig. 1 shows the impact of COVID-19 on GHG emission in the U.S. from 1990 to 2021. The blue column represents the annual change in carbon dioxide in the United States. Among them, the Great Depression, World War II, Second Oil Shock, and 2008 Financial Crisis. Global disasters and the outbreak of COVID-19 had a significant impact on the carbon dioxide emissions of the United States. COVID-19 is the biggest impact on U.S. carbon emissions in nearly 70 years. In Fig.1 (b), China, representing developing countries, Canada and Europe, representing stable developed countries, and the United States, representing the world's most developed countries, have all reduced their annual carbon dioxide emissions due to the impact of COVID-19. It can be seen from Fig.1 A that the decrease of CO2 emission is an index of global major events. During major global events such as the Great Depression, World War II, Second Oil Shock, and 2008 Financial Crisis, carbon dioxide emissions all decreased to varying degrees. And COVID-19 is the worst disaster to reduce carbon dioxide emissions in the United States in 70 years. In Figure 1b, although the four regions show consistent trends of decreasing or slowing carbon dioxide emissions, there are significant differences in the changes of carbon emissions in China, the US and the EU. The reason for such rapid growth in China's carbon emissions is related to the economic stimulus policies adopted by the government in response to the pandemic. Based on the same period in 2019, about 70% of the increase in emissions in the first quarter of 2021 was due to an increase in coal consumption, with oil consumption contributing 20% and natural gas consumption 10%. About 60 per cent of the growth in coal consumption came from the power sector, followed by metallurgy (15 per cent) and building materials (10 per cent, such as cement and glass). In spite of the proposed emission reduction targets in China's steel industry, continued growth in steel demand at the same rate as GDP will lead to an increase in coal-based steel production and carbon emissions. To this end, the central government has asked major energy-intensive industries to peak their emissions by 2025, achieve "stable" reductions by 2030 and "substantial" reductions by 2035 to reduce their impact on the environment. Meanwhile, different stages of development between China and developed countries such as the United States, Europe and Canada explain the increase in China's carbon emissions during COVID-19. Compared with Western countries, which entered the industrialization period as early as the Industrial Revolution, China started its industrial development in the real sense in 1970 when it carried out reform and opening-up. Therefore, the period of high emission in China is exactly the period of high emission in the West.

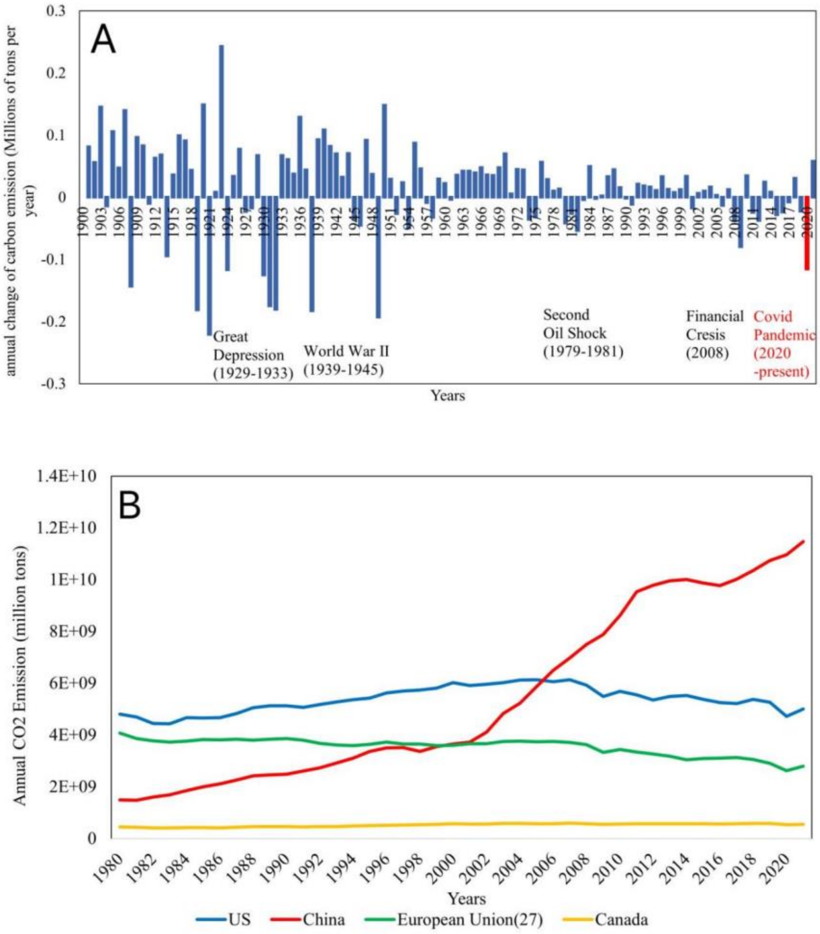

Fig. 1 (a) The Annual Change of Carbon Emission in US from 1900 to 2021. (b) the Annual CO2 Emission of Four Regions from 1980-2021.

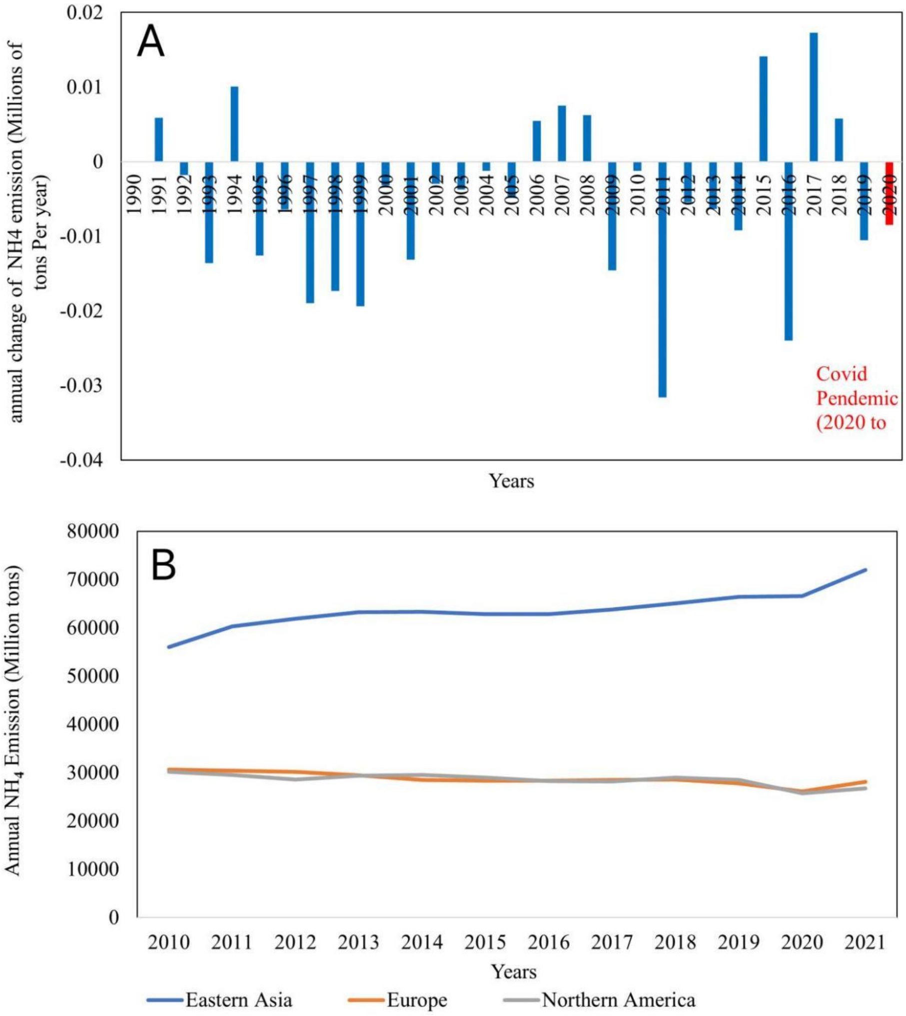

Fig. 2 (a) Annual Change of NH4 Emission in US from 1990 to 2020. Although the COVID-19 outbreak has a small impact on methane emissions, the trend of methane emissions is the same as that of CO2. (b) Annual NH4 Emission of Three Regions from 2021 to 2021. In terms of methane gas emissions, East Asia, Europe, and North America have the same downward trend by 2020.

In Figure 2, we can see that methane emissions have decreased in the United States amid the COVID-19 outbreak, and the same downward trend has been observed in North America, Europe, and East Asia. Methane emissions come from both natural sources and man-made emissions. Natural sources include wetlands and wild animals. The vast majority of human-caused methane emissions come from three sources: fossil fuels, agriculture and waste. Oil and gas extraction, processing and transportation accounted for 23 percent of methane emissions, while coal mining accounted for 12 percent. Landfill and waste water together account for about 20 percent. In agriculture, livestock manure and enteral fermentation account for about 32 percent of emissions, and rice farming for 8 percent. The main reason for the drop in methane emissions is the impact of the COVID-19 pandemic on the world's livestock and oil production.

3.2. Attribution of Carbon Emission

In 2020, the COVID-19 pandemic had a significant effect on the economies, energy markets, and carbon dioxide emissions in the U.S. and the rest of the world. Economic activity and carbon dioxide emissions related to energy began to return to pre-pandemic levels in 2021. In the Fig.3 (b), total energy-related carbon dioxide emissions increased by 7% or 325 million metric tons in 2021 compared to the previous year. However, total emissions in 2021 are still 5% lower than in 2019, or 242 million metric tons. Both short-term and long-term factors contributed to the decrease in carbon dioxide emissions. The increased consumption of petroleum products, particularly in the transportation sector, accounted for more than half of the increase in carbon dioxide emissions in the U.S. In 2020, power generation made up a quarter of the greenhouse gas emissions in the U.S., with fossil fuel burning accounting for almost 99% of emissions in the sector (Smith, 2021). The remaining 1% of emissions in the power sector comes from waste incineration and other technologies, such as renewables and nuclear energy, which produce emissions during the initial stages of raw material extraction and construction.

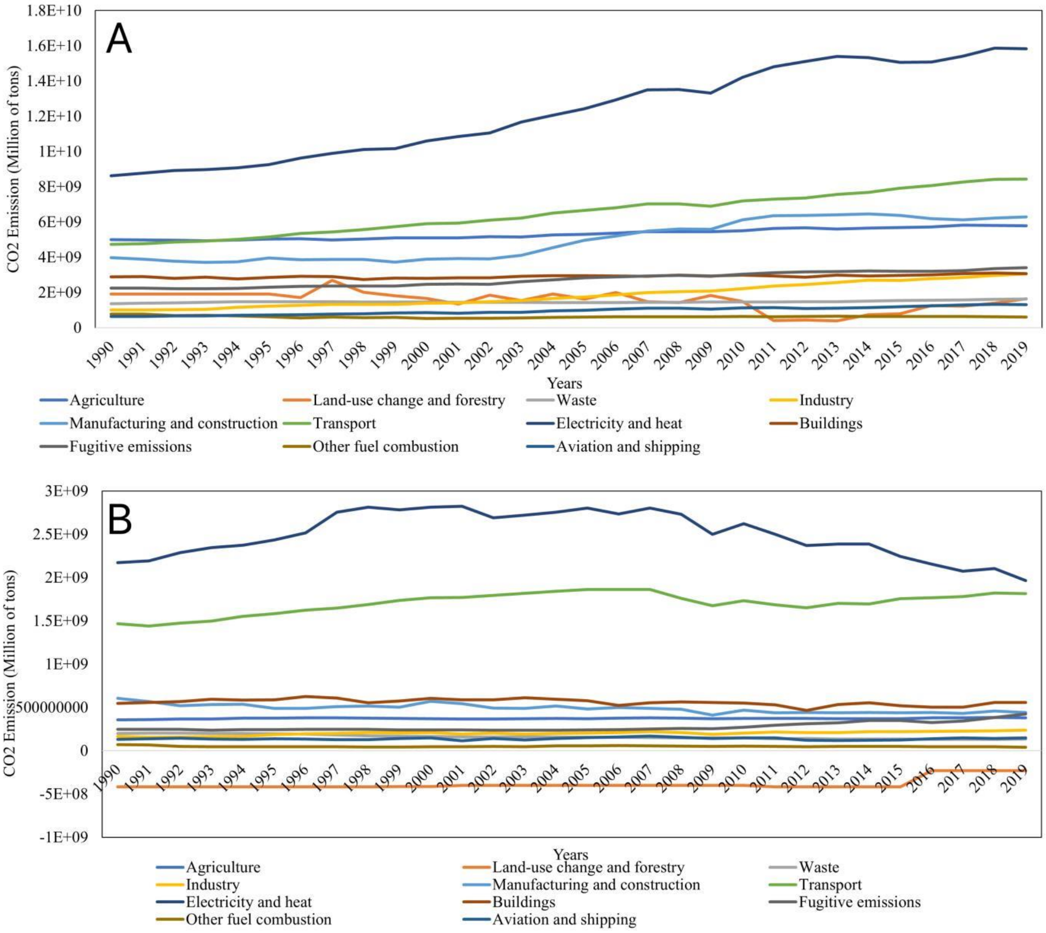

Fig. 3 (a) World annual CO_2 emission from different sectors from 1990 to 2020. (b) US annual CO2 Emission from different sectors from 1990 to 2020.

The COVID-19 pandemic caused a significant decrease in carbon emissions from agriculture, while emissions from other industries remained almost stable (Syed and Asmat, 2021). On a global scale, The COVID-19 pandemic has had a complex and varied impact on carbon dioxide (CO_2) emissions across different sectors. According to Fig3. (a), One of the most significant impacts has been on transportation, as lockdowns and travel restrictions led to a decrease in the number of people using cars and airplanes. This decrease in travel resulted in a significant drop in CO2 emissions from the transportation sector (Syed and Asmat, 2021). In the United States, for example, transportation emissions declined by 18% in April 2020 compared to the same month in 2019. Similarly, in Europe, transportation emissions declined by 25% in April 2020 compared to the same month in 2019. However, the overall impact of the pandemic on transportation emissions has been mixed, with some countries seeing a greater decrease in emissions than others.In the power sector, the pandemic has also had a mixed impact on CO2 emissions. In some countries, the decrease in economic activity led to a decrease in the demand for electricity, resulting in a reduction in CO2 emissions from power generation (Smith, 2021). For example, in India, electricity demand declined by nearly 20% in April 2020 compared to the same month in 2019, leading to a decrease in CO2 emissions from power generation (Sasikumar et al., 2020). However, in other countries, the decrease in demand for electricity was offset by an increase in the use of fossil fuels for power generation, leading to an overall increase in CO2 emissions. For example, in China, coal consumption for power generation increased by 3% in the first half of 2020 compared to the same period in 2019, leading to an increase in CO2 emissions from power generation (Usman, 2021). The impact of the pandemic on CO2 emissions from the industrial sector has also been varied. In some industries, the decrease in demand for goods and services led to a decrease in CO2 emissions (Wang & Su, 2020). For example, in the iron and steel industry, the decrease in demand led to a decrease in production and a corresponding decrease in CO_2 emissions. However, in other industries, such as the chemical and cement industries, the decrease in demand was offset by an increase in the use of fossil fuels for energy, leading to an overall increase in CO_2 emissions (Usman, 2021). In the agricultural sector, the impact of the pandemic on CO2 emissions has been mixed. In some countries, the pandemic has led to a decrease in CO2 emissions from the agricultural sector due to a decrease in the use of fertilizers and a decrease in the number of livestock. However, in other countries, the pandemic has led to an increase in CO2 emissions from the agricultural sector due to an increase in the use of fossil fuels for energy and a decrease in the use of low-carbon alternatives (Naderipour, 2020).

3.3. Comparison of temperature and CO2 emission before and after Covid outbreak

The COVID-19 pandemic has had a temporary impact on temperature change in China, the United States, and the European Union due to the decrease in economic activity and the resulting decrease in emissions of greenhouse gases. However, the long-term trend of increasing temperatures in these regions is expected to continue. Before the pandemic, temperatures in China were increasing at a rate of approximately 0.2°C per decade (Nsabimana, 2020). In the United States, temperatures have been increasing at a rate of approximately 0.15°C per decade. During the pandemic, there was a temporary decrease in CO2 emissions, leading to a temporary decrease in the rate of temperature increase. In the European Union, temperatures have been increasing at a rate of approximately 0.12°C per decade. In Canada, temperatures have been increasing at a rate of approximately 0.2°C per decade. In the global map below, every country or region facing a decrease in the mean temperature. However, as economic activity has begun to recover, emissions have started to increase again, and the long-term trend of increasing temperatures is expected to continue (Nguyen, 2021). To mitigate the impact of the pandemic on temperature change and address the underlying challenge of climate change, it will be important to adopt a range of measures, including the promotion of low-carbon technologies and practices, the development of carbon pricing mechanisms, and the strengthening of international cooperation on climate action. Such measures will help to reduce greenhouse gas emissions and slow the rate of temperature increase in the United States.

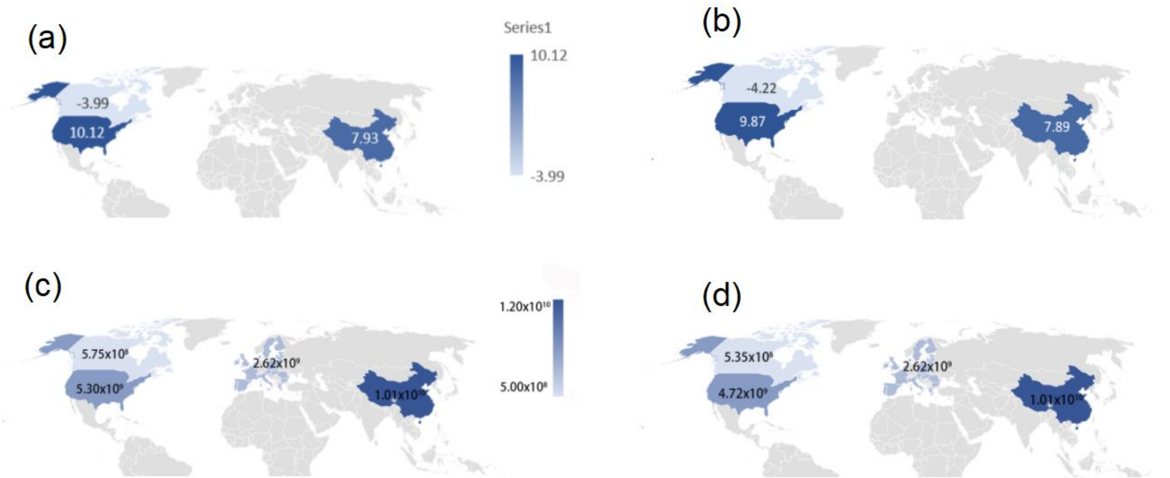

Fig. 4 (a) Global map of Average Annual Temperature from 2015 to 2019. (b) Global map of Average Annual Temperature in 2020. (c) Global map of Average Annual CO2 Emission from 2015 to 2019. (d) Global map of Average Annual CO2 Emission in 2020.

3.4. Relationship among CO2 emission, economics, and climate

In order to understand the exercise of CO2 emission and different factors, Pearson's Linear Correlation was used to calculate the relationship among carbon emission, temperature, GDP, and population between China and the United States, and Two Sample T tests were used to ensure that the correlation obtained was statistically significant (Cleophas and Cleophas, 2018). As two typical countries in different stages of development, China and the United States can well apply the correlation conclusion between data to more countries in the world. In China, the correlation between CO2 emissions and population and GDP is higher than 0.9. One of the main reasons is the close relationship between population size and economic activity (Liu, Zhu, 2020). As China's population has increased, so has its economic activity, which has led to increased demand for energy and contributed to carbon dioxide emissions. Another reason why China's annual carbon dioxide emissions are highly correlated with population is the economy's reliance on the burning of fossil fuels such as coal, oil, and gas (Nsabimana, 2020). These fossil fuels are China's main source of energy and the main source of its carbon dioxide emissions. As China's population grows, so does its demand for energy, leading to the burning of fossil fuels and the resulting increase in carbon dioxide emissions (Liu & Zhu, 2020). In addition to the relationship between population size and economic activity, the structure of the Chinese economy also plays a role in the high correlation between annual carbon dioxide emissions and population (Liu, Zhu, 2020). China's large, energy-intensive manufacturing sector is a significant source of carbon dioxide emissions. As China's population increases, so does the demand for manufactured goods, leading to an increase in the energy used in manufacturing, which in turn leads to an increase in carbon dioxide emissions (Ukhurebor, 2022). In the United States, by contrast, the correlation between annual carbon dioxide emissions and population is very low, mainly because the United States emits relatively much carbon dioxide per person compared to China. Despite having a relatively small population compared with countries like China and India, the United States is the world's second largest emitter of carbon dioxide because of its high energy consumption and reliance on fossil fuels like coal, oil, and gas for energy. As a result, carbon dioxide emissions in the United States are not as heavily influenced by population size as in other countries. Another reason for the low correlation between annual carbon dioxide emissions and population in the United States is the decoupling of economic growth and emissions. In recent years, the United States has made significant progress in reducing carbon dioxide emissions while growing its economy (Eroğlu, 2020). This is achieved through the adoption of low-carbon technologies and practices, the development of carbon pricing mechanisms, and increased international cooperation on climate action. As a result, carbon dioxide emissions in the United States have not increased with population growth. In addition to relatively high per capita emissions and decoupling of economic growth from emissions, the structure of the US economy also plays a role in the low correlation between annual CO2 emissions and population. The US economy is diversified, with both energy-intensive and low-carbon industries. This diversity helps to reduce the overall emission intensity of the economy and leads to a low correlation between CO2 emissions and population (Lahcen, 2020).

Table 2. The Correlation of CO_2 emission, Temperature, GDP, and Population in China and US.

China Correlation	Carbon Emission	Temperature	GDP	Population
Carbon Emission	1	0.710	0.940	0.908
Temperature	0.710	1	0.642	0.798
GDP	0.940	0.641	1	0.787
Population	0.908	0.798	0.787	1
US Correlation	Carbon Emission	Temperature	GDP	Population
Carbon Emission	1	0.225	0.372	0.487
Temperature	0.225	1	0.691	0.674
GDP	0.272	0.691	1	0.974
Population	0.487	0.674	0.974	1

4. Conclusion

There is no doubt that the COVID-19 pandemic has had a major impact globally, leading to numerous deaths and economic struggles due to lockdown measures (Ukhurebor, 2022). However, one potential benefit of the pandemic is the opportunity it provides to study atmospheric CO2 levels during a period of global lockdown. CO_2 is a particularly important greenhouse gas for scientists to focus on because of its ability to absorb heat and its long lifespan in the atmosphere. If CO2 levels are not decreased significantly, we risk facing more frequent and severe weather events and an increase in global temperatures. As a result, it is crucial for the international community to work towards limiting the global temperature increase to 1.5℃ and reducing CO2 emissions. This study describes how the world's carbon emissions and climate are affected at different stages of development in the context of COVID-19. This paper further analyzes the changes of carbon dioxide and methane emissions in the past hundred years, the impact of different sectors on carbon dioxide emissions under the influence of the epidemic and compares and analyzes the changes of temperature and carbon dioxide emissions before and after the epidemic. Pearson's Linear Correlation and Significance Test was used to compare and analyze the relationship between carbon emissions and GDP and population in China and the United States (Cleophas and Cleophas, 2018). The conclusion proves the importance of establishing Zero-carbon economy and coordinating the carbon emission problem caused by global regional development imbalance. However, the study of methane emission in this paper is not complete, and further research is needed to understand why the impact of COVID-19 on methane emission is far less than that of carbon dioxide emission. However, this article will make a great contribution to the prevention of the environmental impact of major global disasters and environmental policy making in the future.

References

[1] Aktar, Most. A., Alam, Md. M., & Al-Amin, A. Q. (2021). Global economic crisis, energy use, CO2 emissions, and policy roadmap amid COVID-19. Sustainable Production and Consumption, 26, 770-781. https://doi.org/10.1016/j.spc.2020.12.029

[2] Barouki, R., Kogevinas, M., Audouze, K., Belesova, K., Bergman, A., Birnbaum, L., Boekhold, S., Denys, S., Desseille, C., Drakvik, E., Frumkin, H., Garric, J., Destoumieux-Garzon, D., Haines, A., Huss, A., Jensen, G., Karakitsios, S., Klanova, J., Koskela, I.-M., & Laden, F. (2021). The COVID-19 pandemic and global environmental change: Emerging research needs. Environment International, 146, 106272. https://doi.org/10.1016/j.envint.2020.106272

[3] Barreiro-Gen, M., Lozano, R., & Zafar, A. (2020). Changes in Sustainability Priorities in Organisations due to the COVID-19 Outbreak: Averting Environmental Rebound Effects on Society. Sustainability, 12(12), 5031. https://doi.org/10.3390/su12125031

[4] Bouman, T., Steg, L., & Dietz, T. (2020). Insights from early COVID-19 responses about promoting sustainable action. Nature Sustainability. https://doi.org/10.1038/s41893-020-00626-x

[5] Cleophas, T. J., & Zwinderman, A. H. (2018). Bayesian Pearson Correlation Analysis. Modern Bayesian Statistics in Clinical Research, 111-118. https://doi.org/10.1007/978-3-319-92747-3_11

[6] Eroğlu, H. (2020). Effects of Covid-19 outbreak on environment and renewable energy sector. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-020-00837-4

[7] Iqbal, S., Bilal, A. R., Nurunnabi, M., Iqbal, W., Alfakhri, Y., & Iqbal, N. (2020). It is time to control the worst: testing COVID-19 outbreak, energy consumption and CO2 emission. Environmental Science and Pollution Research, 28(15), 19008-19020. https://doi.org/10.1007/s11356-020-11462-z

[8] Kapecki, T. (2020). Elements of Sustainable Development in the Context of the Environmental and Financial Crisis and the COVID-19 Pandemic. Sustainability, 12(15), 6188. https://doi.org/10.3390/su12156188

[9] Khan, I., Shah, D., & Shah, S. S. (2020). COVID-19 pandemic and its positive impacts on environment: an updated review. International Journal of Environmental Science and Technology. https://doi.org/10.1007/s13762-020-03021-3

[10] Kumar, A., Singh, P., Raizada, P., & Hussain, C. M. (2022). Impact of COVID-19 on greenhouse gases emissions: A critical review. Science of the Total Environment, 806, 150349. https://doi.org/10.1016/j.scitotenv.2021.150349

[11] Lahcen, B., Brusselaers, J., Vrancken, K., Dams, Y., Da Silva Paes, C., Eyckmans, J., & Rousseau, S. (2020). Green Recovery Policies for the COVID-19 Crisis: Modelling the Impact on the Economy and Greenhouse Gas Emissions. Environmental and Resource Economics. https://doi.org/10.1007/s10640-020-00454-9

[12] Liu, Z., Ciais, P., Deng, Z., Lei, R., Davis, S. J., Feng, S., Zheng, B., Cui, D., Dou, X., Zhu, B., Guo, R., Ke, P., Sun, T., Lu, C., He, P., Wang, Y., Yue, X., Wang, Y., Lei, Y., & Zhou, H. (2020). Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-18922-7

[13] Mishra, J., Mishra, P., & Arora, N. K. (2021). Linkages between environmental issues and zoonotic diseases: with reference to COVID-19 pandemic. Environmental Sustainability. https://doi.org/10.1007/s42398-021-00165-x

[14] Naderipour, A., Abdul-Malek, Z., Ahmad, N. A., Kamyab, H., Ashokkumar, V., Ngamcharussrivichai, C., & Chelliapan, S. (2020). Effect of COVID-19 virus on reducing GHG emission and increasing energy generated by renewable energy sources: A brief study in Malaysian context. Environmental Technology & Innovation, 20, 101151. https://doi.org/10.1016/j.eti.2020.101151

[15] Nguyen, X. P., Hoang, A. T., Ölçer, A. I., & Huynh, T. T. (2021). Record decline in global CO2 emissions prompted by COVID-19 pandemic and its implications on future climate change policies. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 1-4. https://doi.org/10.1080/15567036.2021.1879969

[16] Nsabimana, A., & Jr, E. H. F. (2020). Impact of COVID-19 Pandemic Outbreak: CO2 and SO2 Emission Reduction over China. OALib, 07(11), 1-10. https://doi.org/10.4236/oalib.1106899

[17] Rodrigues, C., & Lowan-Trudeau, G. (2021). Global politics of the COVID-19 pandemic, and other current issues of environmental justice. The Journal of Environmental Education, 52(5), 293-302. https://doi.org/10.1080/00958964.2021.1983504

[18] Sasikumar, K., Nath, D., Nath, R., & Chen, W. (2020). Impact of extreme hot climate on COVID-19 outbreak in India. GeoHealth. https://doi.org/10.1029/2020gh000305

[19] Smith, L. V., Tarui, N., & Yamagata, T. (2021). Assessing the impact of COVID-19 on global fossil fuel consumption and CO2 emissions. Energy Economics, 97, 105170. https://doi.org/10.1016/j.eneco.2021.105170

[20] Syed, F., & Ullah, A. (2021). Estimation of economic benefits associated with the reduction in the CO2 emission due to COVID-19. Environmental Challenges, 3, 100069. https://doi.org/10.1016/j.envc.2021.100069

[21] Ukhurebor, K. E., Aigbe, U. O., Onyancha, R. B., UK-Eghonghon, G., Balogun, V. A., Egielewa, P. E., Ngonso, B. F., Osibote, O. A., Imoisi, S. E., Ndunagu, J. N., Kusuma, H. S., & Darmokoesoemo, H. (2022). Greenhouse Gas Emission: Perception during the COVID-19 Pandemic. BioMed Research International, 2022, 1-12. https://doi.org/10.1155/2022/6166276

[22] Usman, M., Husnain, M., Riaz, A., Riaz, A., & Ali, Y. (2021). Climate change during the COVID-19 outbreak: scoping future perspectives. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-021-14088-x

[23] Wang, Q., & Su, M. (2020). A preliminary assessment of the impact of COVID-19 on environment - A case study of China. Science of the Total Environment, 728(1), 138915. https://doi.org/10.1016/j.scitotenv.2020.138915

[24] Wang, W., Tang, Q., & Gao, B. (2022). Exploration of CO2 emission reduction pathways: identification of influencing factors of CO2 emission and CO2 emission reduction potential of power industry. Clean Technologies and Environmental Policy. https://doi.org/10.1007/s10098-022-02456-1

[25] Wetzels, R., & Wagenmakers, E.-J. (2012). A default Bayesian hypothesis test for correlations and partial correlations. Psychonomic Bulletin & Review, 19(6), 1057-1064. https://doi.org/10.3758/s13423-012-0295-x