# Carbon Emission and Economic Growth within the context of global warming

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**Abstract.** As the global community converges upon the imperative of sustainability and the overarching objective of attaining net-zero carbon emissions, understanding nuanced interrelationships in environmental economics becomes paramount. By comprehending the connection between carbon emissions and economic growth, economies may implement sustainable energy policies and develop energy resources. The main objective of this study is to give a broad overview of the relationship between CO2 emissions and economic development in different countries. Within the framework of this study, historical data have been meticulously collected during the past three decades (1990-2020). The analysis scrutinizes prominent trajectories of GDP and carbon emissions for a cohort of representative nations spanning recent decades, stratifying them in accordance with their stipulated net-carbon emission benchmarks. The denouement of the article accentuates the symbiotic interplay between carbon emissions and economic ascension, proffering sagacious objectives for sovereign entities to contemplate.

**Keywords:** Carbon Emission; Economics/GDP; Global Warming; Sustainability

## 1. Introduction

Ever since the industrial revolution, the world economy has expanded dramatically [1]. The citizens' living quality rises along with the population, thanks to the thriving industries. In spite of the exploitation of the planet which led to a prosperous economy, it was also responsible for an increase in CO2 emissions and a rising level of world temperature. From 1900 to 2021, the world's annual carbon dioxide emissions caused by fossil fuels and industry have risen from 1.95 to 37.12 billion tons, let alone land use change and other factors [2]. The absolute change of average temperature anomaly from 1900 to 2023 is 1.08 degree Celsius and seemingly rising [3].

Such tremendous changes have evidently boosted various disasters from which humankind suffers. The total number of people affected by drought in 2015, for instance, reached 382.99 million while the number was only 20 million in 1920 [4]. From this point of view, it seems vague how the development of humans truly affects themselves, as the increased suffering comes with prospering life as a price. Thus, a controversial issue was born as many countries carried out policies to restrain CO2 emissions, which is the relationship between the carbon emission and economic growth. Much previous research has documented carbon emission and its relationship with macroeconomy for different nations and areas using sophisticated models and data however, the problem still remains on the table. Under the circumstances, most countries have set their own goals to reach carbon neutrality.

In the current global landscape where climate change poses an existential threat, understanding the dynamics between economic development and environmental impact has never been more critical [5][6][7]. The primary aim of this study is to delve deeper into the intricate relationship between economic growth and carbon emissions. Drawing upon various economic models, historical data, and projections, this research seeks not only to elucidate the causal linkages but also to formulate a comprehensive strategy to guide economies. This strategy aims to reconcile economic aspirations with environmental prudence, ensuring that future growth does not come at the expense of ecological integrity. By successfully bridging this gap, it is hoped that economies can transition towards a paradigm of sustainable development, where prosperity coexists harmoniously with environmental stewardship.

## 2. Data and Methods

### 2.1 Choice of typical countries

Multiple nations have set a net-zero emissions goal in the recent years, targeting to accomplish it within a few or more decades, concerning their own conditions. This study typically takes China, the United States, Switzerland, the United Kingdom, and India as subjects.

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To ensure the analysis to be thorough to the greatest extent, the representative countries are selected based on different status of the targets. China, being the world's largest emitter of carbon dioxide, has experienced a significant increase in emissions over the past years and is currently targeting in 2060, in policy document. India's carbon emissions have been on the rise due to its rapid economic growth and expanding population. The nation is currently targeting in 2070, in policy document. The United States, a historically significant emitter of carbon dioxide with a gradual decline in emissions in recent years, pledges in 2050; Switzerland has maintained relatively low carbon emissions compared to its economic output and targets at 2070, not pledged. The UK, having made commendable progress in reducing carbon emissions over the past decade, is currently targeting in 2050 and has made it in law. The status of the nations' net-zero emissions targets can be found from https://ourworldindata.org/grapher/net-zero-target-set.

### 2.2 Data

To reach the goal of this study, indicators of the nations' productivity and carbon emissions are needed for analysis. This study collected the annual emissions of carbon dioxide (measured in tons), the real GDP per capita (measured in current US dollars) and population of each country and combine into curves, as shown in the figures. The data of carbon emissions is adapted from https://ourworldindata.org/grapher/co-emissions-per-capita. The GDP and population data are downloaded from https://data.worldbank.org/indicator/NY.GDP.MKTP.CD.

### 2.3 Correlation analysis and significance test

The statistical method, Pearson's linear correlation, is employed to ascertain both the direction and magnitude of a linear relationship between two variables, effectively excluding alternative potential correlations. The formula to calculate the Pearson's linear correlation coefficient is presented as follows:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \quad (1)$$

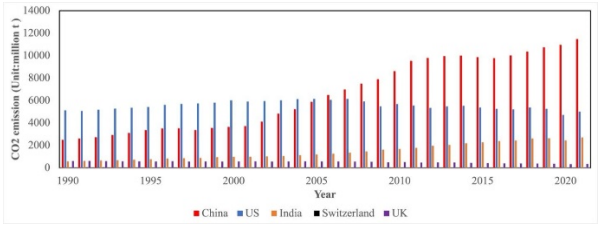
where x and y are two variables or time series, r is correlation coefficient, ranging from -1 to 1 (-1 indicates a strong negative relationship, 0 indicates no relationship, and 1 indicates a strong positive relationship).

Moreover, the Student's t-test, a statistical analysis used to evaluate whether there is a significant difference between the means of two groups, can be used with Pearson's linear correlation. Furthermore, time series of yearly temperature anomalies, carbon emissions, GDP, and energy generation/consumption are subjected to linear regression analysis in order to determine the trend and provide predictions of the future condition.

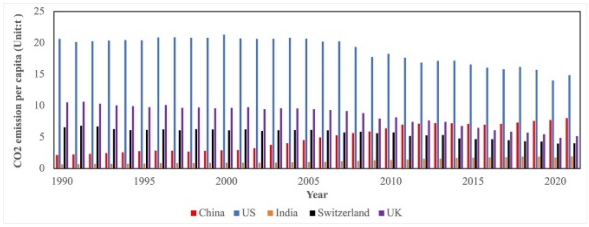
## 3. Results and Discussion

### 3.1 Changes of carbon emission in five selected countries

As shown in figure 1, five nations have shown variations in CO2 emissions in the past decades different from each other. China and India have both shown upward changing in emissions. the former experienced the greatest surge since 2005 and reached the highest of 11000 million tons. The emissions per capita of the two countries, however, are both brought down by their massive population. The United States and the United Kingdom have relatively stabilized their carbon emissions during 1990 to 2020, while there is a considerable gap between the total amount of their emissions. Averagely, the US is letting out about 6000 tons of carbon emissions, which is 5 times bigger than that of the UK. Switzerland, as shown in figure 1(b), has also had a rather constant emissions of about 5 tons per capita. As a sparsely populated nation (Figure 2), it is reasonable why the Switzerland's total amount of emissions is invisible from Figure 1.




(a)




(b)

Fig. 1 Changes of carbon emission in five countries from 1990 to 2021: (a) annual total carbon emission (unit: million t), (b) carbon emission per capita (unit: t). Five countries include China the United States, the United Kingdom, Switzerland and India

### 3.2 Changes of economic development in five selected countries

With a consistently elevated GDP expansion rate, China has seen impressive economic growth. Infrastructure growth, building, and manufacturing have all contributed to this growth. Despite some swings, the United States has kept up a stable rate of economic growth. The nation's persistent progress has been facilitated by its innovative spirit, innovative economy, and cutting-edge technology. With the service sector playing a large role, the United Kingdom has had moderate economic growth. The nation's emphasis on new technologies and growing markets has supported its overall economic stability. Over

the years, Switzerland's economy has remained solid and steady, supported by sectors like finance, manufacturing, and pharmaceuticals. The nation's concentration on Research and development and a knowledgeable workforce have assisted in its economic progress. India's economy has expanded significantly, making it one of the main economies with the quickest growth rates in the world. Along with manufacturing and agriculture, the country's services sector has been crucial in stimulating economic growth.

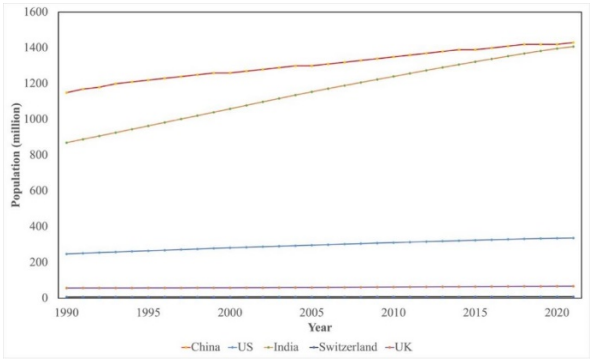
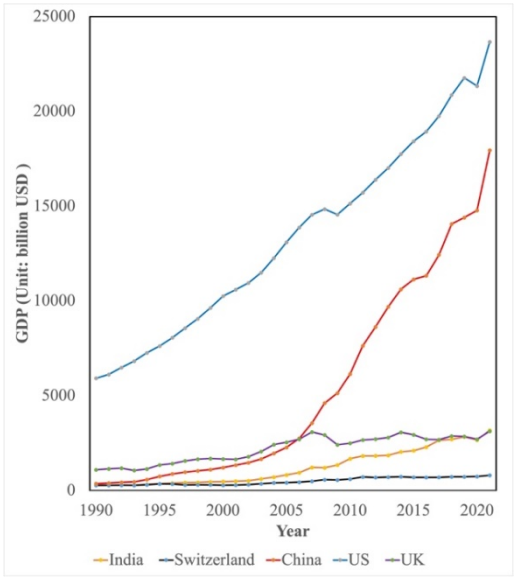
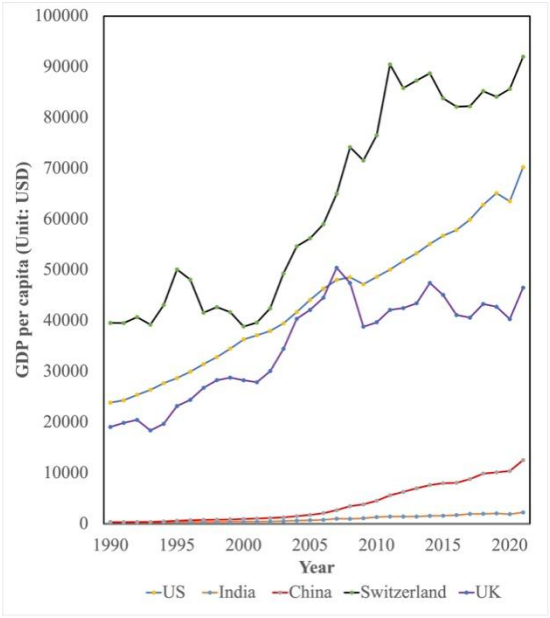



Fig. 2 population of the selected countries

As shown in figure 3, the economic growth of the five countries has shown comprehensive changes during the past 30 years from 2020. China's GDP has thrived the most during the time, as shown in figure 3(a), as its GDP per capita shows a relatively small rise. This may be the result of the samely rising population of about 200 million as shown in figure 2. America's GDP also experiences massive elevation of 20000 billion, as shown in figure 3(a). However, the GDP per capita also boomed especially since 2000 (3(b)), the difference is obviously shown in figure 2, which suggests that the population of the United States only expanded less than 100 million, half of that in China. It is predictable from the figure that the China is looking forward to passing the US in decades. The rest of the countries also experience economic growth of a smaller degree than China and the US. The United Kingdom has a overall growth of 2000 billion in real GDP with a 20000 increase in GDP per capita. India is similar with the China in the relationship between the real GDP and the GDP per capita. A 400 million growth in population leads to a bare rise in GDP per capita of India, with an increase of about 3000 billion in total GDP. Switzerland has shown the clearest boom in GDP per capita, thanks to a lasting growth in GDP and little increase in population.




(a)




(b)

Fig. 3 GDP/ GDP per capita of the selected countries

### 3.3 Relationship between carbon emission and GDP

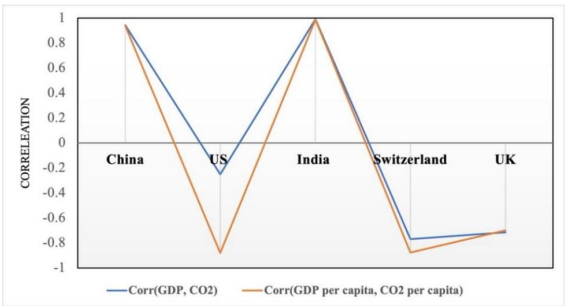



Fig. 4 The correlation curve between GDP and $CO_2$, and GDP per capita and $CO_2$ per capita.

Fig. 4 shows a link between rising carbon emissions and economic development in five selected countries. The nation must strike a balance between environmental sustainability and economic growth. Carbon emissions have increased significantly along with China's booming economy. In contrast, the US has shown that the development of the economy and the level of carbon emissions are not correlated. Despite ongoing economic growth, emissions have decreased as a result of initiatives to switch to cleaner energy sources and boost energy efficiency. This suggests that economic growth can be attained while carbon emissions are decreased. The accomplishment of the United Kingdom in lowering carbon emissions while retaining financial stability emphasizes the possibility for sustainable growth. The nation's policies supporting energy efficiency and renewable energy have been essential in this accomplishment. The relevance of sustainable practices and financial support for renewable energy sources is demonstrated by Switzerland's capacity to maintain low carbon emissions in relation to its economic production. The nation provides as an example of how to balance environmental protection with economic progress. India's economy is expanding quickly, but regulating the country's rising carbon emissions is a concern. To lessen its environmental impact as the nation develops, it must give priority to sustainable practices and invest in renewable energy options. India's long-term viability depends on striking a balance between economic expansion and the decrease of carbon emissions.

### 3.4 Discussion of carbon policy and economics

By 2060, China promises to become carbon neutral. However, this task is really challenging. China will rely on a variety of policies and legislation to fulfill its carbon neutrality targets. Indicators including energy consumption per unit of GDP, carbon dioxide emissions per unit of GDP, non-fossil energy consumption ratio, forest cover, and forest stock are used to measure progress toward carbon neutrality goals [8]. By establishing a clean energy economy that benefits all Americans, President Biden of the United States ran on a bold vision of addressing the climate problem with the urgency that science demands. Switzerland will have emissions reduction targets for the industry sector to reduce emissions by 50% by 2040 and by 90% by 2050 if the public referendum on the country's Climate Protection Act set for June 18, 2023, is successful. By law, the UK government is required by the Climate Change Act to reduce greenhouse gas emissions by at least 100% of 1990 levels (net zero) by 2050. This includes lowering emissions from the devolved governments, which now contribute for around 20% of the UK's emissions (Scotland, Wales, and Northern Ireland). As the third-largest producer of greenhouse gases in the world, India's Prime Minister Narendra Modi set the target for his nation in November 2021: net-zero emissions by 2070 [9].

Amid global climate challenges, nations, including major emitters like China, the U.S., and India, are committing to carbon neutrality and emissions reduction. China aims for neutrality by 2060, while the U.S. and Switzerland focus on clean energy policies. The UK's legal obligations emphasize its green ambitions, considering its devolved regions' contributions. Collectively, these efforts represent a global move toward sustainability, setting the stage for future climate action.

## 4. Conclusion

In conclusion, there are many different aspects to the complicated relationship between carbon emissions and economic growth. The trends in economic growth and carbon emissions in China, the United States, the United Kingdom, Switzerland, and India reflect a variety of experiences and difficulties. While some nations have found a link between rising carbon emissions and economic growth, others have proven the ability to uncouple economic growth from environmental effect. The United States' and the United Kingdom's experiences demonstrate how crucial it is to put in place sensible policies and make the switch to cleaner energy sources in order to cut carbon emissions and spur economic growth. Switzerland is a role model for sustaining low emissions in relation to economic output through environmentally friendly policies and financial support for renewable energy sources. Maintaining a healthy balance between economic growth and environmental sustainability is still a huge problem for nations like China and India. To reduce carbon emissions while achieving their economic objectives, these countries must give priority to sustainable development techniques, such as energy efficiency improvements, renewable energy investments, and environmentally friendly industrial practices [10][11][12].

In general, resolving the connection between carbon emissions and economic growth necessitates a comprehensive strategy that takes into account environmental, social, and economic aspects. Countries can work towards a more sustainable future where economic progress is unconnected from negative environmental effects by implementing effective legislation, adopting sustainable habits, and investing in clean technologies.

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