Proceedings of the 4th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/61/20240951

Decoupling economic growth from carbon emissions: How have Chinese provinces performed in green growth over time?

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Abstract. Extensive research has shown that it is essential to take environmental responsibilities into careful consideration in economic development. Green growth has thereby become one of the most important topics in environmental economics across the globe no matter people are from academia, public, or private sectors. Even though there are many researchers who have investigated the relationship between economic growth and environmental pollution, the vast majority of research has only focused on the absolute amount of economic growth and carbon emissions. In this study, utilizing national statistics about gross domestic product and carbon emissions by region over decades, I not only provide a concrete and comprehensive picture of the green growth of Chinese provinces over time, but also present multiple indicators to capture the growth of carbon emissions and gross domestic product, as well as the growth rate of green growth. The results show that, in spite of a high GDP growth rate, the green growth rate was negative because the carbon emissions growth rate was much higher than the rate of GDP growth. This work has shed some light regarding how Chinese provinces can balance between high economic growth and low carbon emissions in order to have a more sustainable and environment-friendly development path.

Keywords: Environmental Economics, Green Growth, Gross Domestic Product, Carbon Emissions.

1. Introduction

Nowadays, many researchers have been investigating economic development [1]. Economic development is important because it connects to human development on public health, education, income distribution, and investment rate [2]. Economic growth can be defined as long-term rise in the capacity to advance technology, which brings tremendous benefits for the whole population [3]. Economic growth can also be defined as the determination of human development, with wider freedom and greater capability increasing economic development, and human performance would be better regarding to this growth [4].

There are various definitions of economic growth. To begin with [3], defines economic growth as the long-term rise in the capacity to advance technology, which brings tremendous benefits for the whole population. On the other hand, [4] provides another definition. He believes that economic growth is the determination of human development with wider freedom and greater capability increasing economic development.

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In terms of economic growth, there are many investigations in different aspects and areas from previous scholars. The current trend of modelling economic growth is mainly Keynesian. This type of model introduces technical progress that is significant to the economic system, and it also considers the obsolescence in investment and physical equipment [5]. Some other types of economic theoretical models include supply and demand, as well as the theory of normal price [6]. In addition to the theories and models of economic growth, researchers have attempted to understand the factors driving or influencing economic growth. There are many factors of economic growth. One of the most important ones is urbanization because it promotes excessive concentration and capital accumulation [5][7]. Another important research strand is to examine how important the environment is to drive economic growth. Environment and economic growth are related to each other, however, the relationships differ between different countries, it is determined by a country's level on reaching clean energy that can bring a cleaner environment [8][9]. Economic development can put pressure on environmental quality, with an increase in energy consumption that increases economic growth, and policies should be implemented in order to maintain the environmental problems in order [10,11]. Relationships between economic development and the environment are still controversial. However, there is evidence that environmental issues, such as global warming, have been influencing human activity negatively. For this reason, improving the environment would enhance economic growth as it would provide better urban sanitation and other conditions for humans.

Environmental pollution appears in our daily life even from ancient times in which Homo sapiens lighted fires and the smoke from it caused environmental pollution. Nowadays, people heat or cook food, and they also burn fossil fuels; all of these factors contribute to environmental pollution [12]. Mitigating environmental pollution is essential because environmental pollution causes illness. For instance, Escherichia coli is an infectious disease through polluted drinking water. China has developed comprehensive solutions to prevent people from being infected by the illness, and this further proves that the harm of environmental pollution deeply affects human beings. The analyses of the nature of optimal fiscal policy under steady growth indicate that the level of consumption is the source of pollution. If the production tax decreases, the productive public spending would reduce, and production would increase leading to more pollution [13] .

Starting from the Industrial Revolution, human activity in production and material life had been largely abundant, this had also followed by the increased extract of natural resources. The extraction of natural resources had also caused the problem of large emissions of carbon dioxide. Over emission of carbon dioxide would lead to environmental issues like climate change. Thus, transferring the usage of energy to clean energy (green development) is urgent because the continuous of "brown economy" would foster more serious problems, like environmental issues, global climate change, and energy security.

Scientists found that there are close relationships between carbon emission, economic growth and energy consumption. With the development of economic, an increase in energy consumption is inevitable. Therefore, it is important to find alternatives in the area of energy to substitute fossil fuels without affecting economic growth, green development as a result would be a solvency for human beings [14]. The situation that our world is facing can be outlined as first, we need an expansion in Economic opportunities, second, we need to address environmental problems. In the current model of our economy, addressing environmental problems would limit economic opportunities. However, as time passes, unaddressed environmental pressure would undermine the ability to seize economic opportunities. As a result, green development is mandatory as a new type of economic model. Green development refers to promoting economic development and at the same time ensuring the sustainability of environment [15]. Green development is important because the benefits of the green development are considerable. For example, green building in the United State consumes 40% less energy, and releases 35% less carbon dioxide. In addition, green buildings are having higher rental rates, lower vacancy rates, and higher resale value. This supports that green development is having positive impacts in the economy [16]. Achieving green and sustainable development has already become a global priority, and China's national strategy for green development has already been applied to the United States called "Agriculture Green

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Development" (AGD). AGD aimed at rebuilding the entire crop-animal production and food production consumption system which focuses on raising environment-friendly standards. AGD also emphasizes high agriculture production and low environmental impact. The application of AGD to the world would lead to more sustainable development [17].

Currently, Wuhan is a city focusing on automobiles and a city of race. Wuhan is trying to push the green development within the city and advocate for low carbon emissions through political support for large scale sport events to advertise the low carbon emission theory, gaining support from automotive industry scale and scientific and educational. The Strategies that Wuhan uses would be auto racing highlighting the "green" label, auto racing vigorously integrating new energy elements, low carbon operation running through the whole process of race, and using scientific and reasonable traffic control for auto racing [18]. In the global aspect of green development plant nutrition and soil fertility reform is also a predominant strategy. About sustaining solid fertility, the paper emphasizes on importance of balanced fertilization in maintaining high and stable crop productivity, a high level of solid nutrient availability and efficient use of nutrition by crop plants. Fertilizer applications must be chosen because carbon inputs from animal slurry are more important drivers than mineral fertilizer application in increasing soil carbon concentration [19]. The longitudinal analysis focuses on investigating the relationships between companies' environmentally friendly degree and economic performance. The empirical study from this paper demonstrates that environmental orientation and environmental innovation are having positive relationships between each other, and green company can generate same income as no green company with less consumption of capitals, this further support that green company is having a greater ability to generate wealth in the long term [20]. Transferring to renewable energy is a key element for green development, this paper had examined 23 nations about their ability of using renewable energy. With the cross-sectional samples of solar energy including solar, wind, biomass and hydro, user demand mainly reflected in electricity, food preparation, lighting, and production. And the government pattern, financing mechanism, and geographic location are also considered as factors to testify whether it is available or not for the implementation of renewable energy. The result found that energy implementation (<=100kW) would be successfully applied to these developing countries, other factors like socio-cultural political and ecological contexts would also be important determinant of application to renewable energy [21]. However, there are some limits that the previous papers haven't mentioned such as using other types of models to predict the relationships with green development and economic growth. Many of the paper focused specific areas like green buildings or electric cars, our paper would focus on the overall pattern in the relationships of reduce emission of carbon dioxide and economic development.

My paper investigates the relationships between carbon emissions and the growth of economy. I would like to use China as an example to write this because my topic hasn't been investigated by previous scholars. Most of the studies focus on the United States, Nigeria and India, and the methods of exploring this problem focus mostly on Kuznet curves and it is U shaped relationship between economic growth and environmental pollution.

I used China as an example because China is a fast development country in economics, if there is a large connection between economic development and environment, then emphasis on investigating the relationships between environmental pollution and economic growth is necessary. Previously, many people used the country as a unit, but there was not any specific research on province as unit. My study is based on province, so it will be more specific and detailed.

The reason that I use carbon emission as a measure of environmental pollution is because there's a limit of data, since many data only provide the carbon emission instead of other pollutants. Secondly, carbon emission is the main determinant of environment, and environment is highly connected to economic and politic [22].

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2. Data and descriptive statistics

In order to study the relationship between environmental pollution and economic growth, this paper specifically focuses on the relationship between carbon emissions and the gross domestic product (GDP) of Chinese provinces.

2.1. Data about carbon emissions by province in China

I obtained these data about carbon emissions by provide in China from Carbon Emission Accounts & Datasets [17][23]. The original data source is from ceads.net. This dataset contains the carbon emission for 30 provinces in China except for Tibet during 1997 to 2019 in both English and Chinese.

2.2. Data about gross domestic product by province in China

I obtained data about gross domestic product (GDP) of each province in China from Kaggle [24]. The original data source is derived from The National Bureau of Statistics of China. This dataset contains the GDP of 31 provinces from 1992 to 2020 in both Chinese and English.

2.3. Data analysis

Based on the analysis, I did some data processing. At first, I renamed the column names of carbon emission dataset to make it easier to match them with the GDP data. Secondly, because the two data sets cover different periods, I need to match them accordingly leaving the data from 1997 to 2019. Then, because there are only 30 provinces in the data set on carbon dioxide emissions, there is no data for Tibet. Therefore, for the sake of data consistency between the two datasets, I did not include the data of Tibet in the GDP dataset. In the final data combination, there are only 30 provinces, not including Tibet. In addition, I added the region variable. Considering China's geographical factors and China's typical regional economic development characteristics, I think it is necessary to take region as another analytical variable.

2.4. Descriptive statistics

2.4.1. Overall description. Table 1 describes the basic information of the project data. Among them, I looked at data on GDP and CO2 emissions for Chinese provinces from 1997 to 2019. In Section 3 Results, I calculated the growth rate of GDP, the growth rate of carbon emission and the growth rate of green economy. Since the calculation needs to involve the data of the previous year, and the original data does not contain the data of 1996, I did not cover the data of 1997 when I made the result calculation. Therefore, in the analysis of Section 2, I mainly used data from 1997 to 2019; In the analysis of Section 3, I mainly used the data from 1998 to 2019.

Table 1. Data Summary.

Information	Total number
Provinces	30
Time period	1997-2019
Total observations	690
Regions	6

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Table 2. Descriptive statistics of the data.

	Carbon Emissions (Mt)	GDP (100 million CNY)	Ratio
count	690.00	690.00	690.00
mean	252.18	13158.00	57.43
std	242.06	15855.21	59.51
min	0.81	202.80	6.39
25%	95.78	3047.42	24.26
50%	179.12	7374.25	40.23
75%	319.59	17132.00	69.16
max	1700.04	107986.90	636.34

Table 2 mainly describes the basic statistical information of carbon emissions and GDP corresponding to 30 provinces from 1997 to 2019. It can be analyzed from the table that the amount of carbon emission is mainly concentrated between 95.78 Mt and 319.59 Mt, with an average of 252.18 Mt; over the past 23 years, the total average GDP of 30 provinces is 13158.00, in 100 million CNY, the maximum and minimum GDP The value difference is obvious; Ratio is the absolute ratio of GDP and carbon emission, representing the promotion relationship between the two variables.

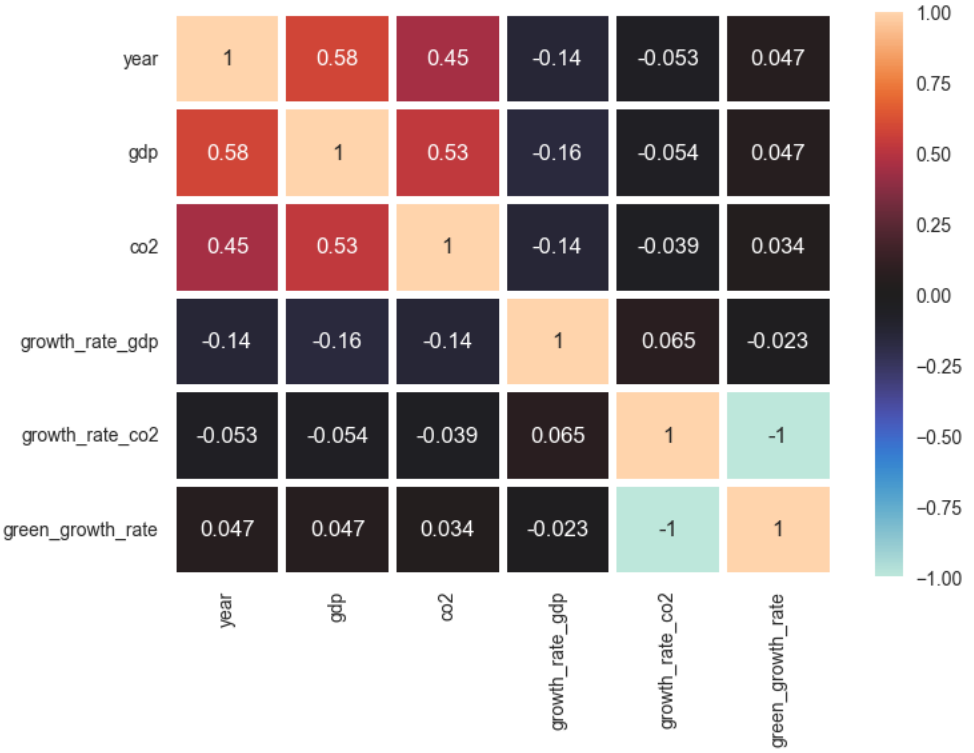

Figure 1. The correlation heatmap among numeric variables.

In this project, I mainly focus on the relationship between carbon emissions and GDP. Figure 1 is a heat map of the correlation between various variables. It can be seen from the figure that the correlation between carbon emissions and GDP has reached 0.53, and it can be concluded that carbon emissions and GDP have a positive correlation, and the correlation is strong. Through this correlation analysis, it also means that the next research of the project is meaningful.

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Pairplot is a chart used to understand the characteristics of a dataset, analyze the relationship between two variables, or classify based on the characteristics of the data. The word graph on the main diagonal of the pairplot chart is displayed as a statistical histogram for each variable, which can be used to understand the distribution characteristics of the data; the sub-graphs on the off-diagonal are scatter plots between different two variables. I can visually discover the correlation between two variables through a scatter plot.

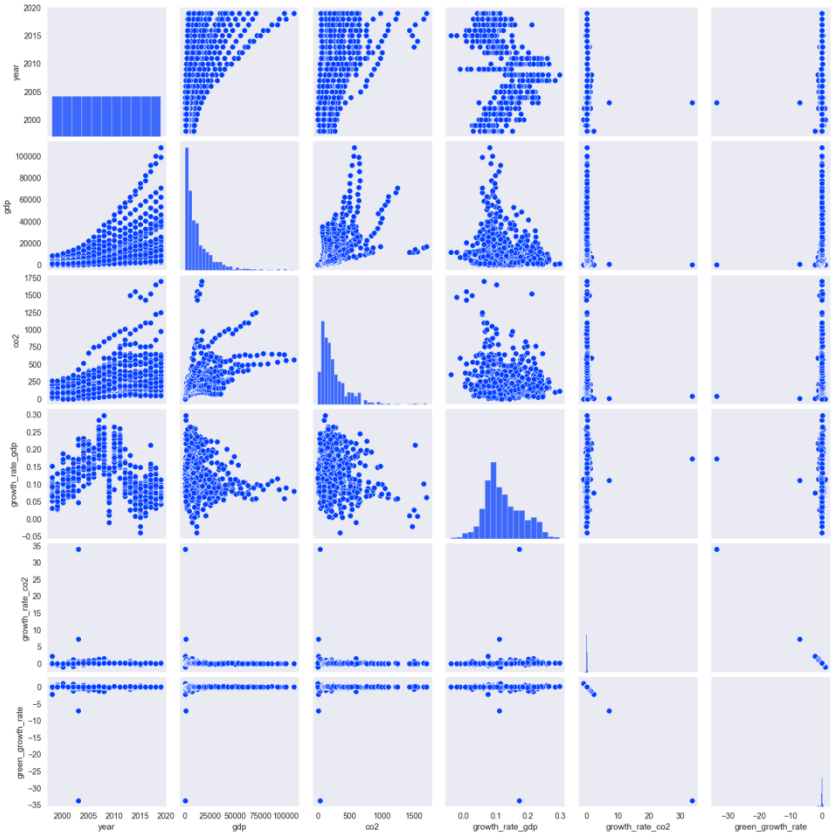

Figure 2. The pair plot of variables.

Based on Figure 2, the relationship between carbon emissions and GDP seems to be linear. However, there are various trends in the scatterplot between these two variables, too. I conjecture that different regions might have different tendencies regarding the association between carbon emissions and GDP. For this reason, Figure 3 depicts the pairplot of variables by region. There are three regions, North China, East China, and South Central China, that have heterogeneity across provinces. More specifically, there are three patterns of provinces in North China: (1) carbon emissions are very high whereas GDP has remained the same, (2) GDP and carbon emissions have been rising at the same time, and (3) while GDP has grown increasingly, the carbon emissions of the provinces from North China have remained a low level. By contrast, in East China, there are four kinds of provinces that followed a positive relationship between carbon emissions and GDP, even though their increase rates were different. As to South Central China, there are two types of provinces, and both types present a pattern in which GDP has been increasing but carbon emissions have remained at almost the same level.

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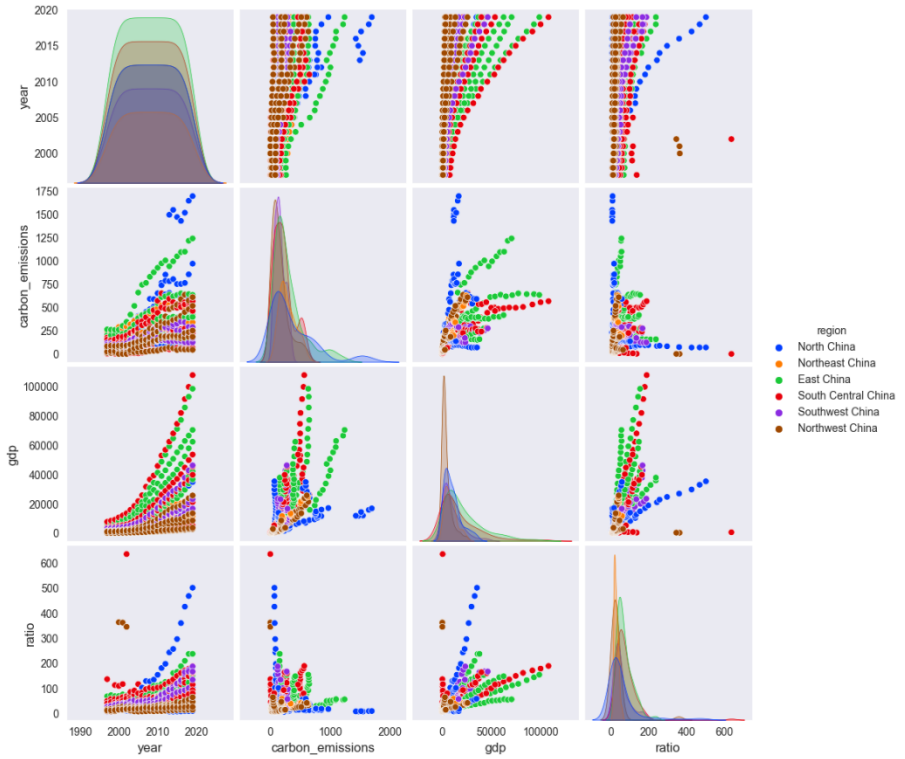

Figure 3. The pair plot of variables by province.

2.4.2. The descriptive analysis about GDP. Figure 4 shows the boxplot of the GDP of provinces over time. According to this boxplot, Guangdong, Jiangsu, Shandong, and Zhejiang were ranked as the provinces that had the highest GDP over time. These provinces had a relatively large variance in GDP as compared to other provinces, especially Hainan, Ningxia, and Qinghai.

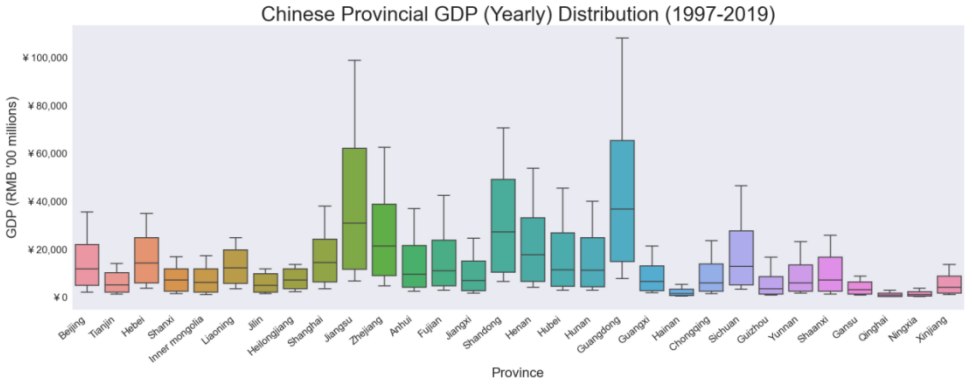

Figure 4. Chinese provincial GDP (yearly) distribution (1997-2019).

Figure 5 provides another perspective of GDP by region and time. Except for those provinces that had a large variance in GDP and led the economic growth in China, some provinces have also made progress in economic development. For instance, Guizhou, Guangxi, and Henan had a steady and fast increase over time in GDP. In addition, those with low variance in Figure 4, such as Qinghai and Hainan, have improved their performance in economic growth over time.

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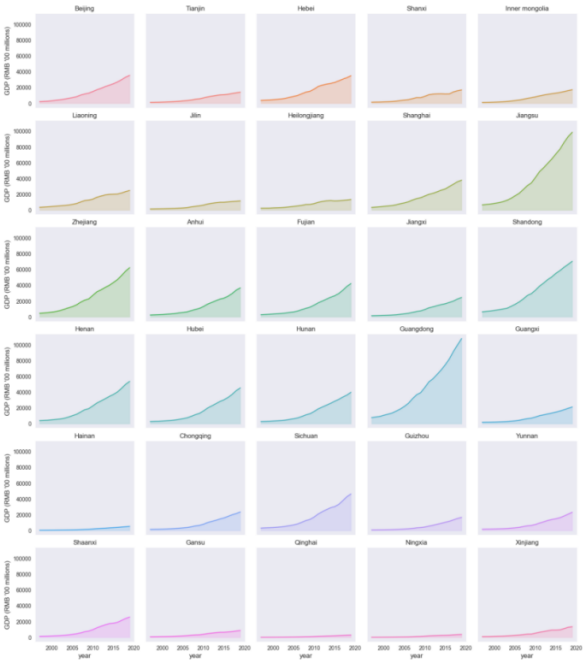

Figure 5. The line chart of GDP over time by province.

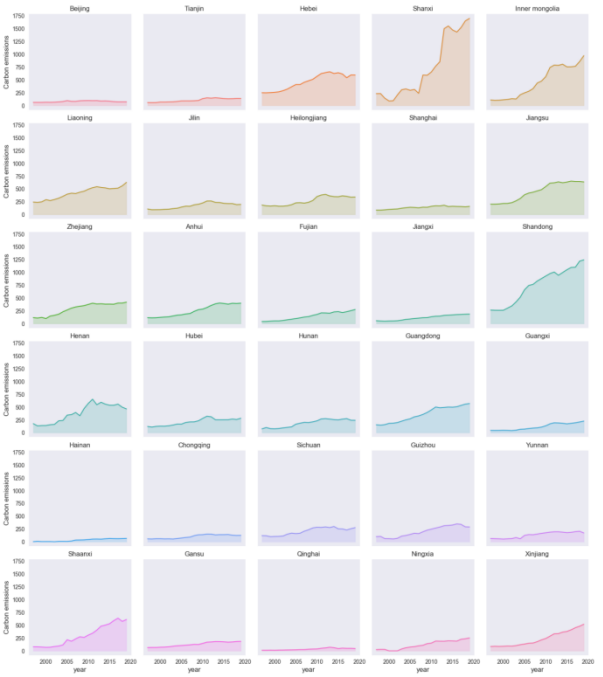

Figure 6. The line chart of carbon emissions over time by province.

The descriptive analysis related to carbon emissions

2.4.3. Descriptive analysis by region. Figure 7 below is a violin plot comparing the differences of GDP and carbon emissions by region. A violin plot generally has two purposes: (1) showing the shape of a data set, and (2) summarizing a data set using five summary values: the minimum, first quartile, median, third quartile, and maximum. In this case, East China and South Central China had the largest variances among data points in GDP, whereas the median values of these two regions were higher than other regions. By contrast, North China and East China had more environmental pollution in carbon emissions. This shows that North China did not perform well in economic growth and, at the same time, did not contribute much to environmental protection.

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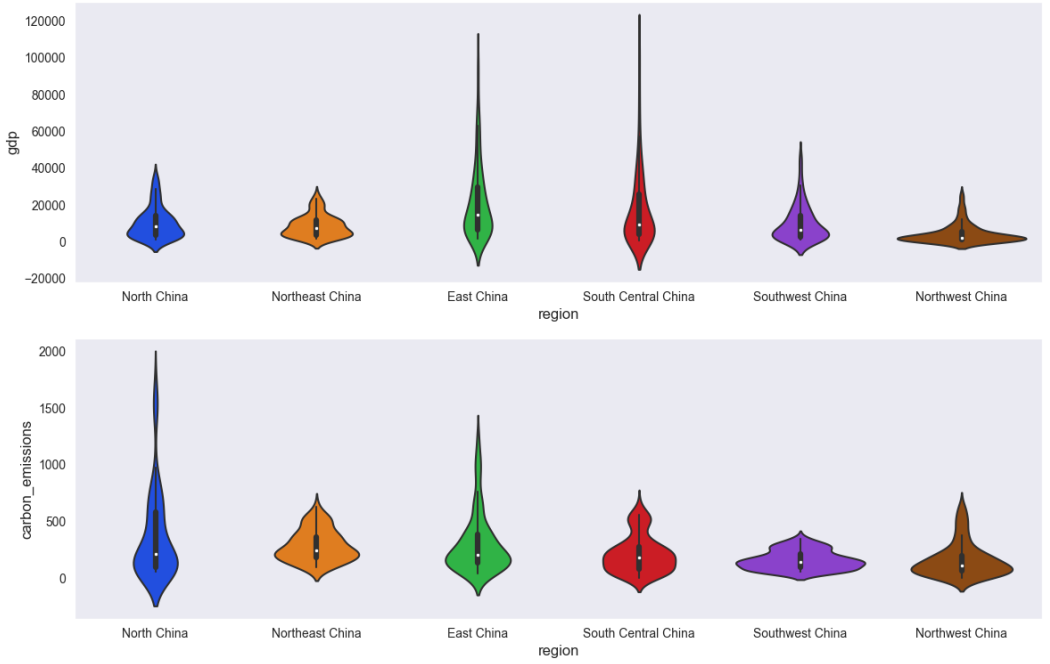

Figure 7. The violin chart of GDP and carbon emissions by region.

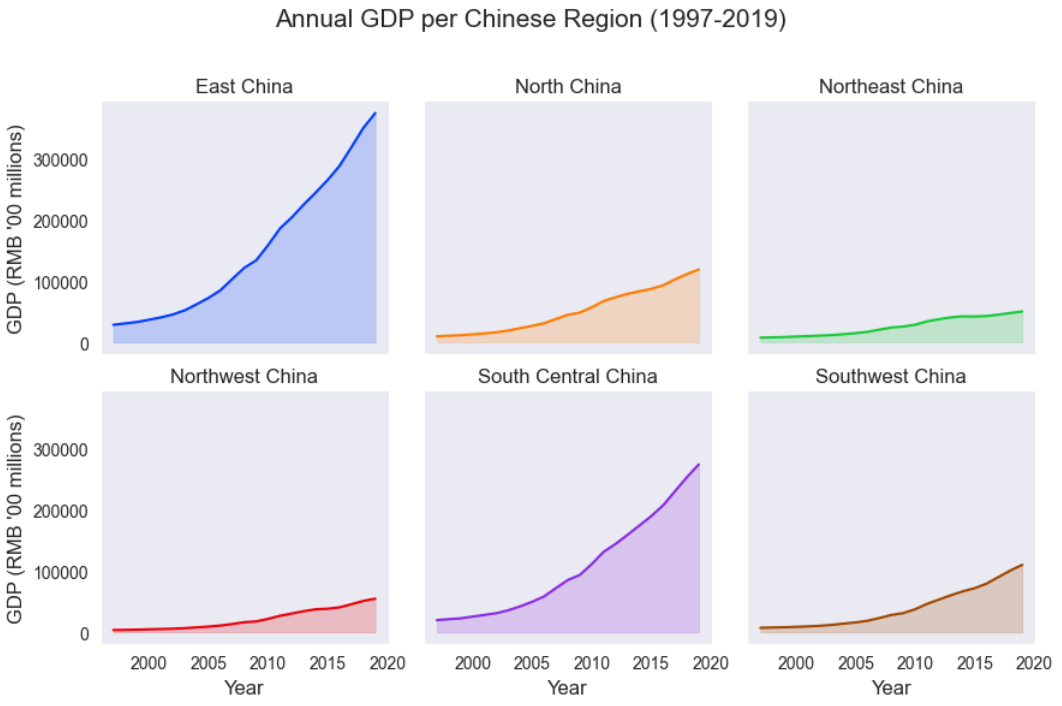

Figure 8. The growth of GDP by region.

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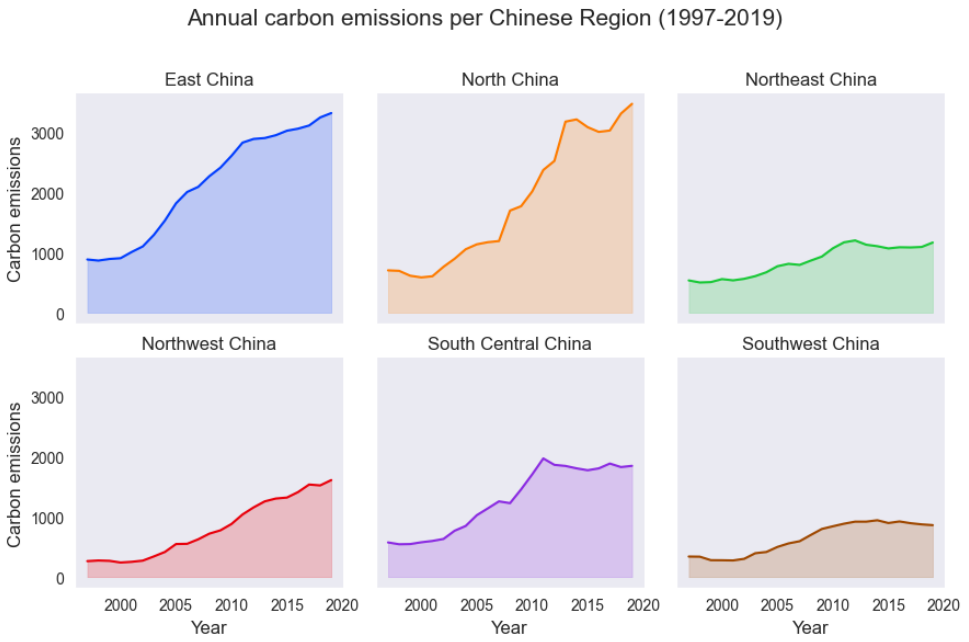

Figure 9. The growth of carbon emissions by region.

3. Results and discussion

In this section, I provide descriptive statistics about economic growth and carbon emissions in Chinese provinces. I am particularly interested in comparing economic growth rates against the growth rates of carbon emissions. Following the green growth concept, countries and provinces should aim at decoupling economic growth from environmental pollution. In my study, I operationalised economic growth as GDP growth and environmental pollution is the growth of carbon emissions.

The formulas of the important results, i.e., the growth rate of GDP, the growth rate of carbon emissions, and the green growth rate are shown as below.

$$GrowthRateGDP_{t1} = \frac{GDP_{t1} - GDP_{t0}}{GDP_{t0}} \quad (1)$$

$$GrowthRateCO2_{t1} = \frac{CO2_{t1} - CO2_{t0}}{CO2_{t0}} \quad (2)$$

$$GreenGrowthRate_{t1} = GrowthRateGDP_{t1} - GrowthRateCO2_{t1} \quad (3)$$

The following three charts show how these three important indicators evolve over time. Ideally, provinces see their GDP grow over time, whereas the carbon emissions decline or remain constant. A high difference or increasing difference between GDP growth and carbon emissions can be regarded as green growth. The figures show various patterns and I compare the similarities and differences between Chinese provinces and terms of GDP growth and carbon emissions.

To begin with, several provinces show an increasing GDP with stagnant carbon emissions. For example, the gross domestic product of the region of Guangdong has increased steadily. At the same time, the carbon emissions have increased until they reached a plateau. After that, they remained roughly constant for the subsequent years. I suggest that these provinces have increasingly grown their economies without increasing their carbon emissions, which is in line with the green growth concept.

More specifically, Figure 10 describes the green growth rate the picked the difference between the growth rate of the gross domestic product (GDP) and the gross rate of carbon emissions of each Chinese province. The difference between GDP growth and carbon emission growth is measured in percentage points. If there is a difference of 0.5 percentage points, then this means that the growth rate of GDP is

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0.5 percentage points higher as compared to the growth rate of carbon emissions. The charts show how this difference has changed over time.

For example, in Beijing, the green growth rate has almost always been positive since 2000. Only around the year 2005, the green growth rate was below zero. This means that the rate of growth of GDP in any year has been higher than the growth rate of carbon emissions in Beijing. For instance, in the year 2015 the green growth rate in Beijing was around 0.25. This indicates that the growth rate of GDP was roughly 0.25 or 25 percentage points higher compared to the rate of growth of carbon emissions. This is a big difference.

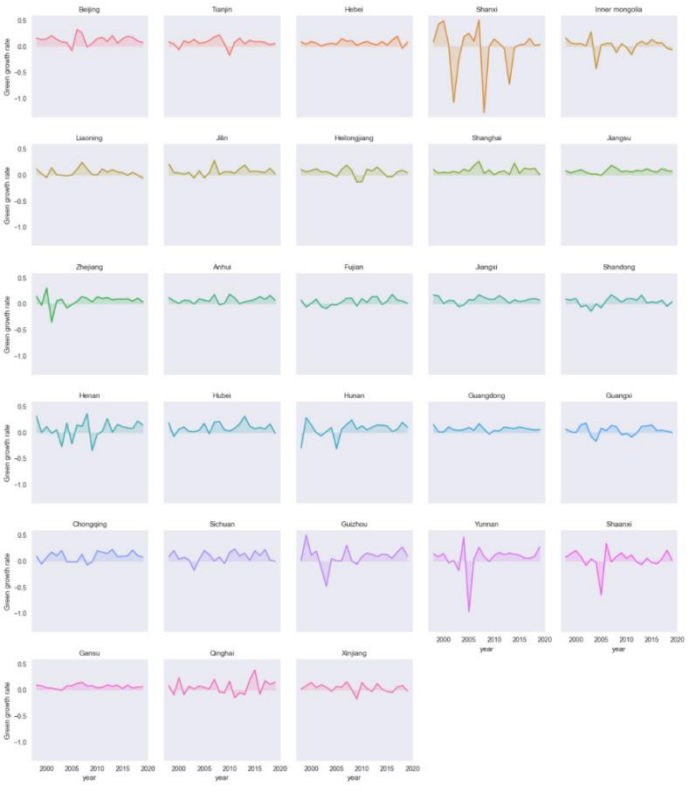

Figure 10. The green growth rate over time by province.

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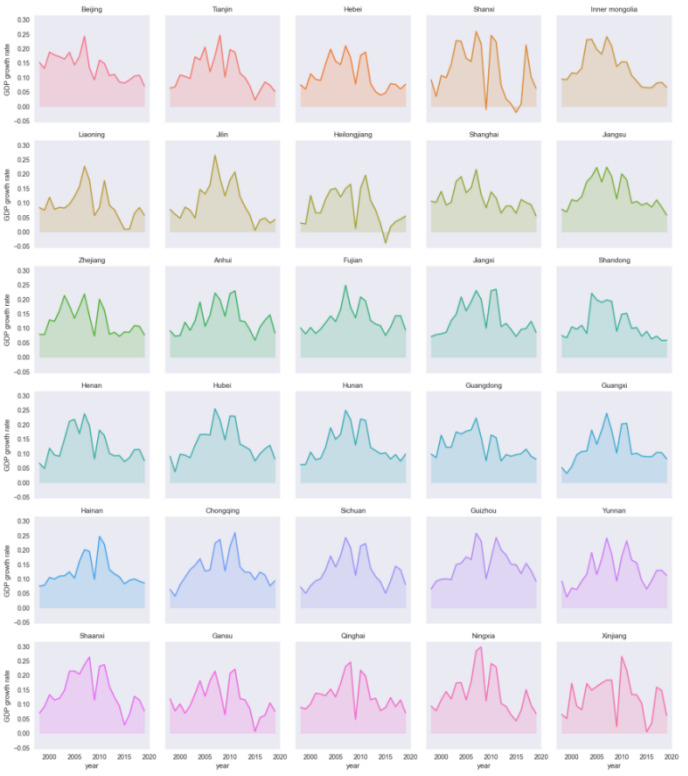

Figure 11. The change of GDP over time by province.

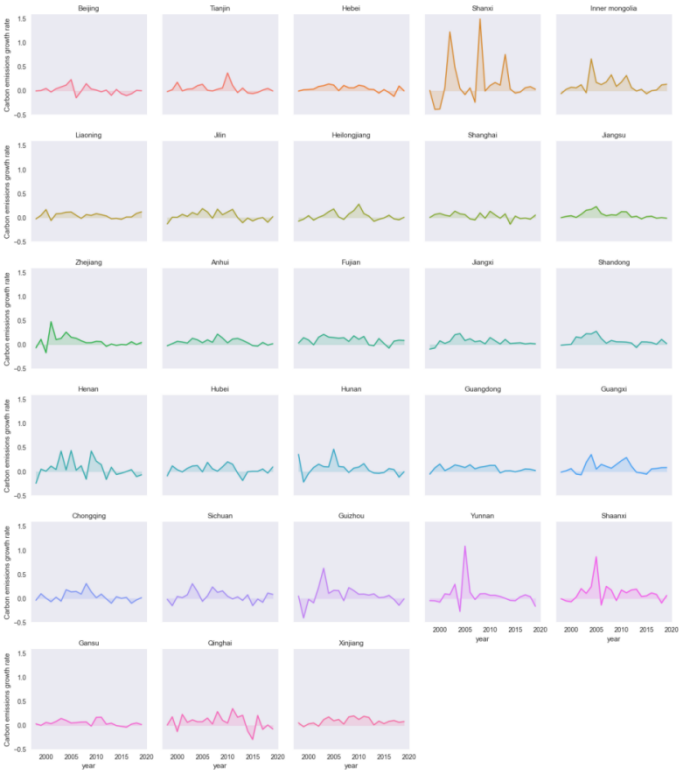

Figure 12. The change of the growth rate of carbon emissions by province over time.

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4. Conclusions

In this study, I investigate the relationship between economic growth and carbon emissions across time periods and provinces in China. Overall, in spite of a high GDP growth rate, the green growth rate was negative because the carbon emissions growth rate was much higher than the rate of GDP growth. This work has shed some light regarding how Chinese provinces can balance between high economic growth and low carbon emissions in order to have a more sustanaible and environment-friendly development path.

Specifically, in most provinces, the rate of growth of GDP has been higher than the rate of growth of carbon emissions in most years. Some provinces have even experienced continuous green growth, meaning that the rate of GDP growth has almost always been higher than the rate of carbon emission growth. This pertains to the provinces Beijing, Hebei, Shanghai, Jiangsu, Guangdong, Gansu, and Hubei, Chongqing, and Anhui.

Moreover, it is worth noting that six provinces experienced a sharp decrease of the green growth rate around 2005. And this year, these provinces reached a value of almost -0.5. This indicates that the difference between the GDP growth and carbon emissions growth was almost 50 percentage points at that time. In this case, the negative value indicates that the rate of carbon emissions growth was around 50% higher than the GDP growth rate. Such a pattern applies to Shaanxi, Shanxi, Guizhou, Inner Mongolia, and Zhejiang.

Why did this happen? A look at the other two charts shows that the GDP has actually increased in these provinces in the year 2005. However, the carbon emissions have increased even more. In fact, there was a spike in carbon emissions in these provinces in 2005. Put differently, the growth rate of carbon emissions reached its peak in 2005. In spite of a high GDP growth rate, the green growth rate was negative because the carbon emissions growth rate was much higher than the rate of GDP growth.

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