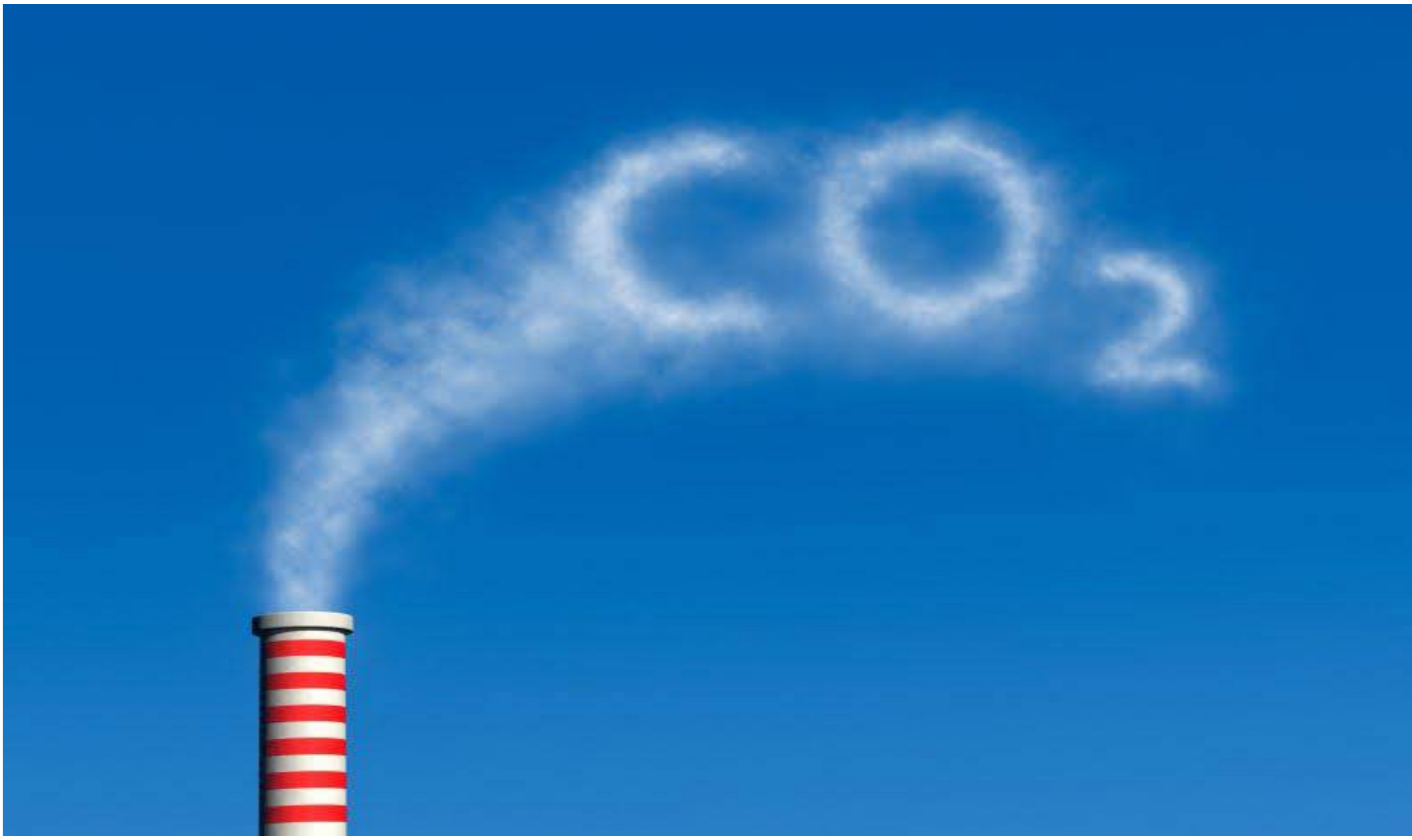
A Research on The Changes on the Carbon Emissions in China in The Phase of New Normal



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By

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Acknowledgements

The spring of 2020 is different from previous springs I've experienced. Over the past six months, the COVID-19 pandemic has disrupted people's daily life all over the world and made my 2-years master program even shorter. I used to have plenty of plans for the last semester of my student life, but finally spent most of my time alone at home, facing the computer screen. It is not easy to write a thesis during such a special period, but thanks to many people, the journey became more fun and positive.

I want to extend my gratitude to my first supervisor, Dr. Enno Schröder, and daily supervisor Rayne Wu, for their patient guidance and constant support on the thesis. At first, I found it not easy to find a suitable topic and spent much time on it. It is Enno who helped me find my area of interest and guided me to this challenging topic. In the following writing process, I made lots of mistakes, but they always helped me through. The knowledge they shared with me and the suggestions they gave means a lot in working on the whole project.

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Besides, my thanks would go to my mom and dad for their unreserved love throughout these years. I definitely won't be who I am today without their support and encouragement. They always want to give me the best things in the world, and their love gives me the courage to face the world. I also want to thank my boyfriend, Xiaoliu. We've known for nine years and have witnessed all the important moments for each other ever since. His love and company mean a lot to me and I hope we can always stant together in the future.

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Shitao Cai

Executive Summary

Global warming is one of the most significant concerns for human beings today in the 21st century. Lots of evidence shows that greenhouse gases induced by human activities are the main reason causing global warming. In the Fifth Assessment Report issued by Intergovernmental Panel on Climate Change (IPCC), scientists warn that if people don't restrict carbon emissions to an acceptable level, the earth will suffer a serious ecological crisis. Under this circumstance, countries and regions around the world are taking action to reduce greenhouse gas emissions.

The 2009 World Energy Statistics (IEA, 2009) announced that in 2007, China had exceeded the United States and became the country with the most carbon dioxide emissions in the world. Though China is still a developing country, the country is always trying to keep a balance between economic development and environmental benefits. In 2007, the State Council of PRC formulated National programs on Coping with Climate Change, intending to achieve zero or even negative growth in CO2 emissions by the middle of the 21st century. In 2016, the Chinese government published the 13th Five-Year Plan for Economic and Social Development. In this report, the government promised to decrease the carbon emission per unit of GDP by 60% to 65% before 2030 compared to 2005. In order to reach the carbon reduction targets, we first need to have a thorough and comprehensive study on the key factors which influence carbon emissions in recent years and then make policy adjustments accordingly.

In this thesis, the main question is: What are the changes in China’s carbon emissions, and what are the main drivers that affect it in different stages of economic growth? The main question can be answered through several subquestions.
-What is China's economic structure? To be more specific, what is the final demand structure, and what is the production structure? And how does the structure changes in different phases?
-What is China’s carbon emission structure? And how it changes in a certain time period? For example, what are the changes in the CO2 emission rate, and what are the changes in energy patterns?
- From a demand perspective, which component contributes the most to GDP and carbon emissions? How much carbon dioxide was emitted by domestic demand, and how much by foreign demand? Within the domestic demand, how much was emitted by consumption, and how much by investment?
-What are the main influencing factors of carbon emissions? How do they affect the total CO2 emissions, and what are the underline reasons for it?

For the methodology, this paper uses the WIOD database to constructs an input-output model of economic growth and carbon emissions from final demand perspective, and then studies the impact of changes in different final demand (consumption, investment, export) structure on carbon emissions between 2000 and 2014. After that, the paper uses SDA method to studies the impact of five key driving factors (population, carbon emission intensity, industrial structure, consumption structure, economic growth) on China's carbon emission growth from 2000 to 2014 and find the main drivers for the growth in different stages.

The analysis results show that the total CO2 emitted by China’s production sector in 2014 has increased by 294,5% compared with it in 2000. The increase of per capita GDP is the key factor which drives the growth of CO2 emissions during that period, and contributed 93,5%

of the increase while other factors remaining unchanged. Consumption structure and production structure contributed 63,3% and 28,5% of the growth respectively; carbon emission intensity offset 91% of the increase; the effect of population was not significant.

In this research, we divide 2000-2014 into three stages: 2000-2007 is the stage before the financial crisis, 2007-2010 is the stage during the financial crisis, and 2010-2014 is the stage after the financial crisis which is also called the new normal. During 2000-2007, the proportion of CO2 emissions from China's consumption continued to decline, while the carbon emissions from exports and investment increased rapidly. During 2007-2010, the 2008 global financial crisis lead to a decline in China's exports declined, and CO2 emissions from export decreased sharply, while carbon emissions from investment increased rapidly. From 2007 to 2010, over 40% of China's CO2 emissions growth was brought about by investment. The increase in investment mainly came from the Chinese government's four trillion economic stimulus plan in response to the financial crisis and the recession afterward, which mainly focused on strengthening the domestic infrastructure construction. After 2010, the share of carbon emissions from exports has further declined, and the share of consumption has increased slowly. Carbon emissions from investments have always dominated.

From 2000 to 2010, the improvement of carbon intensity serves as the key driver in offsetting China's CO2 emissions, and while keeping other driving forces unchanged, it offset 42% of carbon emissions from 2000 to 2010. The structure of production and consumption patterns promoted the growth of China's carbon dioxide emissions at this stage, with the rates being 31% and 12% respectively. After 2010, China's economic development has entered a new normal, and both production structure and consumption structure contributed to the decrease of carbon emissions. Per capita GDP was very significant in promoting the growth of CO2 emissions; the demographic effect was insignificant. It can be seen that through economic production structure adjustment and technological innovation, the increase in CO2 emissions can be largely suppressed.

Based on the analysis above, this article proposes some policy recommendations for the four driving factors with significant influence: 1. Make the consumption structure changes from the investment- and export-driven structure to a consumption-export-investment coordinated structure. 2. Further develop the production structure reform from mainly relying on the secondary industry to a synergistic among all the three industries, the first industry, the secondary industry, and the tertiary industry. 3. Develop new technology and introduce management innovation methods to increase carbon efficiency.

Reducing carbon emission is a systematic project that needs time and efforts . There is no doubt that this research will help us to understand the carbon emissions in China better and then help control it in the future, and the management of technology is one of the most useful methods for it.

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1. Introduction

1.1 The Concern about Global Warming Worldwide

Climate is an essential part of the natural environment on which human society can continue to develop. Any change of climate will affect the natural ecosystem, human economic and social life greatly.

Global warming pertains to the gradual heating of the Earth's surface, atmosphere, and oceans mainly induced by human activities (Peters, 1990). In 2013, the IPCC Fifth Assessment Report (AR5) was released. Through thorough research on the global ecosystem, the report shows that the past decades have witnessed unexpected changes in the ecosystem. The iceberg has melted, sea level has risen, the temperature of the atmosphere and ocean has gone up, and the greenhouse gases in the atmosphere has concentrated(Stocker et al., 2013). The risk of global warming is already around us.

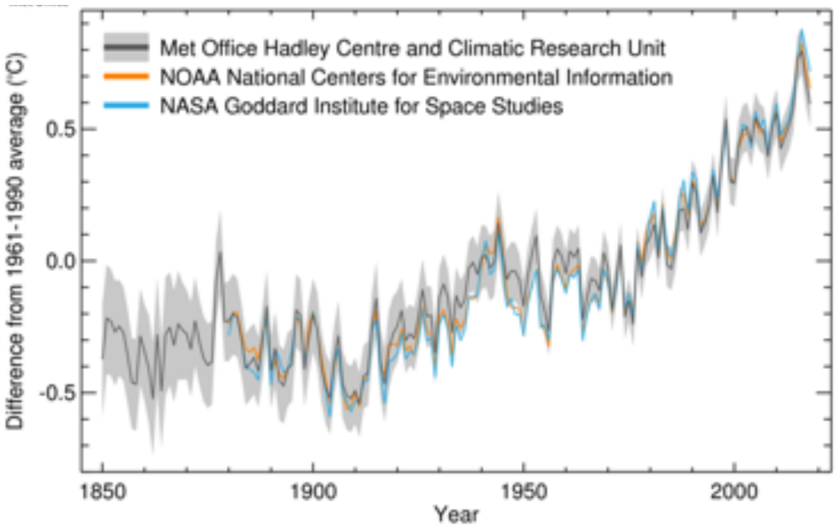

Figure 1 Global mean temperature anomalies, with respect to the 1850-1990 baseline(Source: UK Met Office Hadley Centre, https://www.metoffice.gov.uk/hadobs/monitoring/index.html)

Global temperatures have been increasing over the years. Figure 1 shows the global temperature change for each year from 1850 compared to the average global temperature from 1961 to 1990. The black line is data from the HadCRUT4 dataset showing the world's annual land surface temperature (LST) on average from1850 (Jones et. al., 2012) . The grey zone is the confidence interval of 0,95 on the annual average temperature. And the blue line is the world's annual temperature data derived from the NASA Goddard's Global SurfaceTemperature Analysis(GISTEMP) data set (Lenssen et al., 2019). The orange line is the world's annual temperature data from the National Climatic Data Center's NOAA Global Surface Temperature (NOAAGlobalTemp) data set (Menne et. al., 2018). The baseline is set as the annual temperature from 1961-1990 on average. According to the AR5, LST had increased by 0.85 °C from 1880-2012. Between 1902 to 2015, due to the thermal expansion of the ocean as well as glacial melting, the average global sea level has risen by 16b centimetres, and the rising rate is still accelerating. What's more, the concentration of CO_2 (391ppm) and CH_4 (1803ppb) in the atmosphere in 2011 far exceeded the range of natural changes in the past 800.000 years (Stocker et. al., 2013).

Though there is more and more evidence that the global temperature is increasing and there are potential risks, global CO_2 emissions are still increasing. And if greenhouse gas emission is not restricted under some rules, the increase of global temperature may exceed between 0.3 to 4.8 °C at the end of this century, and the atmosphere, water cycle, ocean, cryosphere, and other biogeochemical cycles will be severely affected (Stocker et. al., 2013).

Exports believe that global warming is one of the biggest challenges facing human beings in this century for which the main driver is human activity(Iqbal & Ghauri, 2011). There are many potential risks resulting from climate change. For example, it will lead to increases in extreme weather conditions like El Niño and will rise sea-level greatly, forcing many people to leave their homes. It will also lead to degrading ecosystems and natural resources, and then affect crop growth and human health, further harming the whole society as well as economy. Continued uncontrolled greenhouse gas emissions will stimulate and intensify the negative effects of the global climate change well in the future (Steffen et al., 2018).

As early as the early 1980s, the United Nations has appealed to the international community to care about climate change issues. In 1988, the United Nation (UN) and the World Meteorological Organisation (WMO) created an organisation together with the name of Intergovernmental Panel on Climate Change (IPCC). The aims for the organisation is to provide the world with objective and scientific information about climate change induced by human activities, its impacts on the nature and society, potential risks and possible countermeasures. In 1992, United Nations Framework Convention on Climate Change (UNFCCC), the very first convention to combat climate warming was adopted in Rio de Janeiro with an aim to maintain the concentration of greenhouse gases in the environment at an acceptable level that would protect the ecosystem from dangerous changes and anthropogenic interference (Bodansky,1993). Later, in Kyoto, Japan, the 1997 United Nations Climate Change Conference (COP3) was held and during this conference, the Kyoto Protocol was ratified. The protocol established three cooperation mechanisms-the International Emissions Trading Mechanism (ET), the Joint Implementation Mechanism (JI), and the Clean Development Mechanism (CDM), and stipulated that the developed countries should reduce carbon emissions by 5,2% during the first commitment period of 2008-2012 compared to 1990. The kyoto protocal is the first step in achieving international cooperation to reduce CO_2 emissions. In 2009, the Copenhagen Accord was signed, where countries reached a consensus to control the global temperature increase below 2 °C by 2050. However, due to the dispute among countries, the specific reduction target for each country was not decided. Later in 2016, in Paris Agreement, a more specific 20/20/20 targets (reduce CO_2 emissions by 20%, increase the market share of clean energy and renewable energy to 20%, and increase energy efficiency by 20%) was proposed as the aim in the second half of the 21st century (Rogelj et. al., 2016). In 2019, the United States announced its withdrawal from the Paris agreement, and until 2020, there are still 195 countries that approved the agreement.

Table 1 Important Events and conferences for global climate change, (Source: Xinhua News Agency)

Year	Events
1988	UN and WMO cooperated to establish IPCC
1990	The United Nations initiated the process of negotiations of UNFCCC
1992	UNFCCC was adopted in New York, United States and later, over 150 countries signed it at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil

1994	UNFCCC became effective from this year
1995	The 1995 United Nations Climate Change Conference which was also named as the first conference of the Parties to UNFCCC (COP1) was held in Berlin, Germany and a new round of negotiations was started to strengthen the obligations of Parties; IPCC published the second assessment report
1997	The 1995 United Nations Climate Change Conference (COP3) was held in Kyoto, Japan, and during this conference, “Kyoto Protocol” was adopted, which set the targets of CO2 emission reduction for developed countries
2001	IPCC published the third assessment report
2002	COP8 was held in New Delhi, India, and The Delhi Ministerial Declaration on Climate Change and Sustainable Development was announced
2005	Kyoto Protocol became effective from this year
2007	COP13 was held in Bali, Indonesia, and Bali Road Map ws adpoted; IPCC published the 4th assessment report
2009	COP15 was held in Copenhagen, Denmark, the Copenhagen Agreement was proposed as a supplement of the Kyoto Agreement and the global reduction goal from 2012-2020 was discussed
2010	COP16 was held in Cancún, Mexico, and an agreement for “ Green Climate Fund” was adopted
2011	COP17 was held in Durban, South Africa, and the second commitment period of Kyoto Protocol was discussed
2013	COP19 was held in Warsaw, Poland, the loss and damage compensation of climate change was discussed

The reason why international climate negotiations have repeatedly fallen into a deadlock is the distribution of responsibility. Historically, the industrialization process and high economic growth are accompanied by a large amount of energy consumption and corresponding high CO2 emissions, and figure 2 illustrates this trend. Europe which started the industrial revolution earliest in the world used to account for 90% of global emissions. After that with the development of the United States, its emission proportion gradually increased, and in 1916 it became the largest emitter. In 1945, the CO2 emitted by the United States accounted for half of the world’s total carbon emissions. After World War II, the economies of countries around the world began to develop and recover, and energy consumption besides Europe and the United States has grown with a high speed, becoming the new major source of carbon emissions (Narayan& Saboori, 2016). Because of that, the Kyoto Protocol affirms that developing countries have less obligation to reduce emissions, while developed countries should take more for their historical emissions. However, the developed countries led by the United States require developing countries like China and India to undertake emission reduction responsibilities as well, which was quite difficult for developing countries.

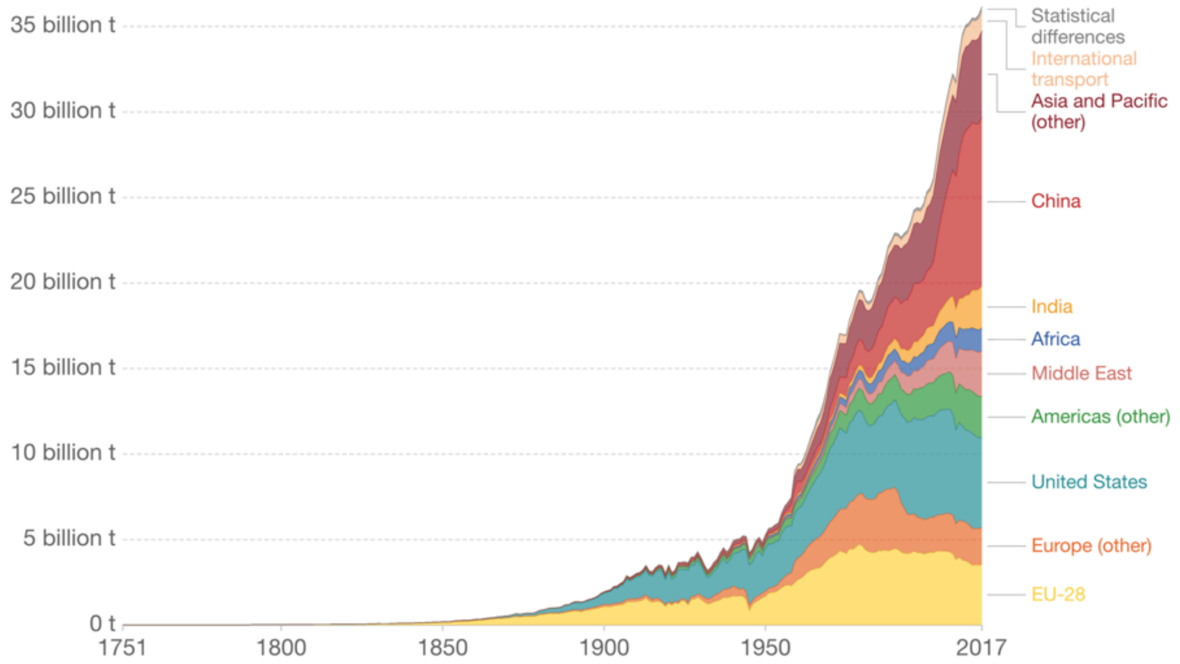

Figure 2 Annual Total CO2 Emissions, by world region from 1751-2015 (Source: https://ourworldindata.org/grapher/annual-co-emissions-by-region)

Because of that, nowadays, while developed countries can reduce carbon emissions with an aim of 0% growth, the challenges facing developing countries are bigger: they want to keep their economic growth while having the aim of reducing the growth rate of CO2 emissions. Developing countries account for over 70% of the world's land area and total population so it is important to help them develop a way with both economic growth and reduction of carbon emissions.

1.2 Why We Use Final Demand to Evaluate Carbon Emissions

In an open economic system, economic activities of different countries are intertwined because of international trading. Production and consumption activities are geographically separated, so there are always discussions on how to allocate the carbon emission reduction responsibilities among countries. Now, there are two conflicting methods to measure greenhouse gas emissions: the production-based method and the consumption-based method. Production-based emissions occur within a nation's territory and territorial water in which the country has its own jurisdiction (IPCC, 2006). This theory is supported by most developed countries. Rothman (1998) and Joseph (2005) found that through importing products from other countries developed countries kept a high-emission lifestyle while reducing their carbon emission. Therefore, the production-based principle is unfair and will help developed countries to retain carbon emissions and other pollution in developing countries, which is not conducive to realizing the global carbon emission reduction targets.

On the contrary, consumption-based emissions consider the impact of international trade, and the final CO2 emissions in this method include emissions from domestic final consumption and also emissions from the production of imported products. Bastianoni, Pulselli, and Tiezzi (2004) pointed out that the consumption-based responsibility is fairer because it is the last user who bears the responsibility for carbon emissions, and in the meanwhile, it avoids the problem that developed countries shifted their carbon responsibilities to developing countries.

So we use the consumption-based principle in this thesis to evaluate China’s carbon emission and emission reduction responsibility.

Final Demand refers to the sum of consumption, investment, and export demand in a country or region within a certain period (usually a year), and it affects the developing speed and quality of the entire national economy. For the energy consumption perspective, changes in final demand affect the flow of energy resources both directly and indirectly. On the one hand, energy is directly consumed by citizens or used for investment and export purposes. On the other hand, it is consumed during the production processes while the products or services will finally be used as final demand, which indirectly increases energy consumption. To conclude, the change in final demand affects the change of energy consumption and therefore influences the CO2 emission.

1.3 Current Status in China

1.3.1 Economic Status

China is the second-largest economy in the world and the largest developing country. As shown in Figure 3, over the past 40 years, the country has experienced rapid economic growth, with the gross domestic product (GDP) reaching 10.4 trillion U.S. dollars in 2014 (NBSPRC, 2015). The journey of economic growth is not always smooth, especially in the 21st century. In 2001, China joined the WTO, which marked the beginning of a period of rapid economic development with investment and exports grew quickly. The annual GDP growth rate on average between 2000 and 2008 was more than 10%. Then later in 2008, the financial crisis swept the world. An important member of the international economy, China's economy was also greatly affected. The average annual GDP growth rate decreased from 14% in 2007 to around 10% in 2008 and the growth rate continued to decline. In 2014, the GDP growth rate dropped to 8%. Of all the final demands, the export market has suffered the most. In 2008, China's exports fell by nearly 40% (Mi et al., 2017). In order to tackle the negative effects of the global economic recession and keep a stable domestic market, the government responded quickly. The Chinese government put forward the "four trillion plan" in December 2008, focusing on infrastructure construction and people's livelihood projects (Meng-xing, 2012). With the help of all these efforts, China's economy began to recover slowly, and the demand structure of the Chinese market has changed. However, the Chinese economy cannot return to the previous growth rate and enter a new stage of development as it did before the crisis, which the Chinese government calls the "new normal". The "new normal" means a shift in China's economic development model, focusing on better quality growth. This kind of growth is more sustainable in terms of economy and environment and is conducive to the realization of a better standard of living for the Chinese citizens (Green & Stern, 2017). Under the environment of global warming, China’s attitudes and actions on greenhouse gas emissions have become crucial.

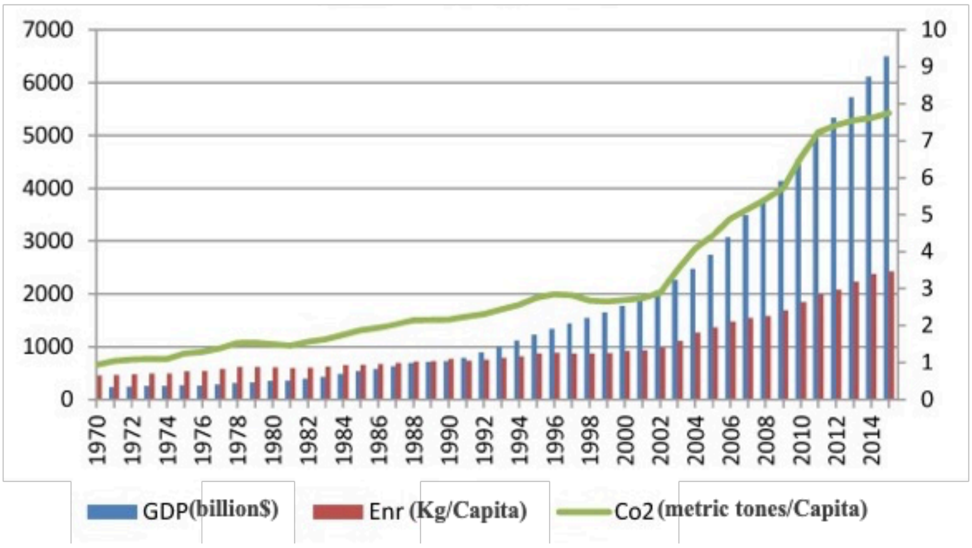

Figure 3 The GDP, energy consumption CO2 emissions in China from 1970 to 2015 (Sorce: https://www.sciencedirect.com/science/article/pii/S0959652617318358?via%3Dihub)

1.3.2 Energy Consumption Status

China is in the process of accelerating urbanization and industrialization with the characteristic of intensive exploitation and rapid consumption of natural resources. The contradiction between the limited energy resources and urgent demand for economic growth has been increasing. In 2000, the total energy produced in China was 1385.7 million tons of standard coal equivalent (Mtce), and the total energy consumption was 1469,6 Mtce. The energy gap was 83.94 Mt. In 2014, the gap became 639.4 Mt, was still increasing (NBSPRC,2015). Such an energy-reliance economic growth model has caused a series of environmental problems, and CO2 emissions are one of them. In 2009, the International Energy Agency(IEA) released the World Energy Statistics, announcing that in 2007, China had emitted 6,03 trillion tons of CO2 which surpassed the United States and became the largest carbon emitter in the world (IEA, 2009). In 2012, China's carbon emission was already equivalent to the total emission of Europe and the United States (IEA, 2015). The gradually severe environmental problems gave huge pressure on the Chinese government. As a developing country with a population of more than 1.3 billion, a high proportion of secondary industry in the industrial structure, and a relatively backward technological level, China has great potential in reconstructing energy structure and reducing carbon emissions.

The Chinese government has always been an active participant in tackling the issues of greenhouse gas emissions and has ratified a lot of international environmental conventions including UNFCCC, Kyoto Protocol, and the Paris Agreement. In 2007, the National Development and Reform Commission of People's Republic of China (NDRC) officially released the "National Programs on Coping with Climate Change", which was the first policy paper in China dealing with the climate change issues. The report clearly stated China would strive to achieve zero or even negative growth in carbon emissions by the middle of this century (2007, NDRC). In June 2007, the State Council proposed 43 specific measures including economic restructuring, development of low-carbon and renewable energy, afforestation, family planning, etc., in its workplan for carbon emission reduction, proposing to stabilize CO2 emissions (State Council, 2007). In the Copenhagen Conference in 2009, the Chinese representative expressed the government's commitment to reduce carbon intensity by 40-45% before 2020 compared to it in 2005. In 2011, the State Council published the 12th Five-Year Plan for Economic and Social Development, which promised to save energy consumption by 670 Mtce from 2011-2015 (State Council, 2011). And in 2016, the Chinese government published the 13th Five-Year Plan for Economic and Social Development, which promised to decrease carbon emission per unit of GDP by 60% to 65% in 2030 compared to 2005(State Council, 2016).

1.4 Research Motivation and Research Questions

1.4.1 Research Motivation

It is obvious that China has witnessed a sharp increase in both economy and carbon emissions in recent years. From Figure 3 it becomes more clear that ever since 2000, the increase faces three differnet stages: before the financial crisis when the increse rate was fast, during the crisis when the curve became flatter and after the crisis when China was seeking a new way for sustainable development which is called the new normal. Before the crisis, there is a rapid increase in GDP and CO2 emissions; during the crisis, the increase rate of GDP and CO2 emissions decreased and the changing rate was quite high; after the crisis, the the increase rate has become slow but steady.

The reason for the different performances in carbon emissions in specific stages is complex, and it is imperative to analyze the historical development to find out the factors that cause the changes and then conceive further strategies to help reducing carbon emissions while keeping a steady economic growth. Besides, the policies which are responsible for the changes are worthy to be analyzed.

In conclusion, this research aims to find the relationship between the changing economic structure and CO2 emission especially when entering the phase of "New Normal". Thus we can make evaluations on the value of previous economic changes on the environment and give suggestions and recommendations for further policies adopted in the new normal stage to better control CO2 emission and protect the environment while keeping economic growth.

1.4.2 Research Questions

The main research question is the main focus of thesis research. Besides, to answer the main research question more clear, some subquestions are developed. The answers to these subquestions become important components of the answer to the main question. The main question and following subquestions are as follows:

Main research question

-What are the changes of China's carbon emissions and how does the rebalancing of China's economic structure affect it?

As we mentioned above, China now is entering a new development stage with lower growth speed and a healthier economic structure. Protecting the environment as well as reducing carbon emissions to a certain target is an important aim in the "New Normal" stage, the whole country is taking action. So it is important to know whether the changes help reduce carbon emissions and how it is achieved.

Based on the main research question, there are two main building blocks. The first one is about the changes in China's growth model, there are two subquestions. The following questions will be answered based on the literature review and descriptive data analysis.

-What is China's economic structure? For example, what is demand structure like, and what is the production structure? And what are the changes over the years?

This question mainly focuses on the development of China's economy and the carbon policies and targets applied over time. It will provide a comprehensive description of China's economic performance and features in different stages and show the changes from different perspectives. All these are important for further analysis of the changes in greenhouse gas emissions.

-What are the changes in CO2 emissions over time and what are the changes for the influencing factors? For example, what are the changes in the CO2 emission rate and the energy consumption rate?

The answer to this question will provide the basic information about the energy consumption history in this country and give an overall what is the changes in CO2 emissions during the selected period, which benefits further analysis.

In the second block, we detailed discuss the CO2 emission for different final demand and the driving factors for the changing emssions. In this block, two analytical methods, the input-output model and structural decomposition analysis method are applied to find the relationship between facgtor changes and CO2 emission changes. The subquestions are as followed:

-Which component contributed most GDP and carbon emissions in demand perspective? How much CO2 was emitted by domestic demand and how much by foreign demand? Within domestic demand, how much by consumption and how much by investment? And how much GDP was produced by each demand sector?

To answer this question, we use the input-output method to calculate the GDP and carbon emissions in each year from the perspective of different final demand(export, consumption, and investment) and get the exact differences between years. Besides, we can also measure the carbon efficiency for different final demands during a certain period to see in which sector the energy usage is the most efficient. All these conclusions provide data support for the analysis " What are the changes of final demand structure over time and how the changes affect CO2 emissions". By comparing the changes in different time period we can evaluate the influence of New Normal stage. Also, the calculated data are required for further analysis in the next subquestion.

-What are the driving factors of carbon emissions? How do they affect the total CO2 emissions and what are the underline reasons for it?

In this subquestion, the SDA model will be applied to calculate the contribution of each driving factor to the total CO2 changes during the different time periods. Besides, we would like to discover the reasons behind the changes in the main contributors and then find proper explanations for it. Thus we can have a clear view of what are the differences after entering the New Normal phase and evaluate the effectiveness of the new developing stage in controlling carbon emissions. Further, based on all the analysis we do above, the suggestions of what China could do in the future to reduce greenhouse gas emissions to meet the zero-emission growth target by 2050 can be provided.

1.4.3 Knowledge Gap

The study of CO_2 reduction has been a hot spot over the past years and there are many studies about the influencing factors of greenhouse gas emissions in China. For example, Zhang (2013) discussed how the changes of China's final demand structure affect the energy consumption from 1995-2009 and found that the CO_2 emissions increased by 214.41% due to the increase of domestic demand. Zheng et al. (2017) discussed the embodied carbon emissions from 1992-2020 for 29 industry producers. The result shows that fixed capital formation and urban residential consumption are the two most important drivers for the changes in CO_2 emissions from the perspective of final demand. Guo (2012) discussed the impact of changes in the industrial structure on China's carbon emissions from 1996-2009 and found that changes in the proportion of high energy-consuming industries in all industries would lead to changes in industrial structure effects, which would affect carbon emissions. Du (2019) used the data from 1996-2016 to study the effect of technology improvement on reducing carbon emissions and found that the improvement of technology and optimization of energy consumption structure are two effective ways on helping reduce carbon emissions.

From previous studies, we can see that considering the influencing factors of carbon emissions, most studies only focus on one main factor, such as demand structure, production structure, and technology, and the time period chosen is quite random. Such studies can only answer one question: how a certain factor change affects the overall carbon emission. It is not enough as the changes in certain factors don't always come alone. For example, the decrease in export between 2007-2009 is due to the 2008 financial crisis, and the changes of the proportion of the high-consumption industry rely much on the government policy. Having a more comprehensive view will help in making recommendations on further reducing carbon emissions.

In this research, I want to improve my reserch from the following aspects:

1) Besides the data analysis, I would like to find the relationship among the changing carbon emissions, demand structure, the economic environment and the policies applied in China to get a more comprehensive conclusion on what factors affect the changes of carbon emissions and give suggestions suggestions on how to better reduce carbon emission with healthy economic development in today's economic environment of new normal.
2) I would like to choose the time period 2000-2014. In these fourteen years, there are three representative stages of economic development: 2000-2007 represents the period of high growth, high pollution; 2007-2010 is a period of financial crisis which enforce the country to think about another developing way; between 2010-2014, there is the start of the new developing mode which have deep influence for the next decades. By investigating the changes in those three stages, we can find what our current status is and give suggestions more suitable in our current economic environment.

1.5 The Structure of the Thesis

This study mainly focuses on how the changes in demand structure influence the greenhouse gas emissions as well as economic growth in China and what is the main driver for it. On the one hand, we would like to find the political guidance behind the structural changes by literature review. On the other hand, we also use analytical methods to find the correlation among them and find the reasons for it. Based on that, this report can be divided into the following six chapters.

Chapter one is the introduction part of the thesis. This chapter describes the background, the research questions, knowledge gap of the study and shows the structure of the report.

The second chapter mainly explains the economic growht in China and corresponding carbon emissions in different stages, making an analysis of energy structure changes and gives a comprehensive view on the policies and targets for carbon emissions in detail. The concept of "New Normal" will be explained more clearly in this chapter.

Chapter three introduces the research methodologies in this study. It includes the introduction of the WIOD database and the data chosen, a detailed introduction of two analytical models, the input-output model and structural decomposition model, and a brief introduction of the software used during the research process.

The analytical results are shown in chapter four. The input-output analysis will decompose the total carbon emission into the different categories of final demand and a comparison of the results over time will be studied to see the trends of carbon emissions and which part of final demand accounts most for the carbon emissions. After that, a structural decomposition analysis is conducted. The analysis will decompose carbon emissions with the main driving forces. The analysis will present the most important driver of the carbon emission overall and for each final demand category.

In Chapter Five, the five main drivers for carbon emissions will be presented, their contribution to carbon emissions will be calculated accordingly. Based on the analysis, we can have a clear view that which factor caused the increase or decrease of carbon emissions and which one is the most important driver in certain stages and discuss in detail the five influencing factors.

Chapter six discusses the research results and gave corresponding policy recommendations based on the results. Afterward, the reflection is done on the knowledge learned in the research project. The advantages and limitations of the report are also discussed.

1.6 MOT correlation

This research is mainly a empirical study on carbon emissions in China and provides some recommendations for governments and companies on how they could reduce carbon emissions in the future. One of the most important methods is to develop new technologies and introduce innovation management to increase carbon efficiency.

During the research process, the knowledge I learned from the MSc Management of Technology was applied. The basic concepts and presuppositions of the economic modeling were learned from the economic courses. The specialization "economics and finance" includes following cources “economic foundations”, “intermediate economics”, “economics and finance” provide me an overview of the economic ; and elective “economic policy for sustainable energy” deepen my interest in energy economy. In different stages of the economy, the decision-making process always exists in deciding the development strategy and making new environmental policies that will be reflected in the changes in carbon emissions. And responsibility innovation is an idea throughout the report. Only environmentally friendly technologies are welcomed nowadays. As this study was empirical research focusing on scientific theories and numbers, it is more similar to an academic view than guidance which can be used directly in the real world. When combining the result to the real industry, it could be more helpful and more comprehensive. For example, if it forms as instructions to high energy-consumption companies on reducing CO2 emissions, besides the overall suggestions, there could be more specific ideas on how to change the proportions of energy and which technology can be applied to improve the efficiency.

2. China's Economic Growth and Carbon Emissions

China, with the official name of the People's Republic of China, is a socialist country located in East Asia. It is the second-largest country in the world, covering approximately 9.6 million square kilometers. It is also the most populous country in the world and by 2020, the total population is expected to exceed 1.4 billion. Since the beginning of free-market reforms and "opening up" foreign trade and investment strategies in 1978, China has made significant economic progress. From 1978 to 2017, China's GDP increased by 33.5 times, with an average annual growth rate of 9.5%, which means that China can double its GDP every eight years (Figure 4) (NBSPRC, 2018). The World Bank describes it as "the fastest sustained expansion of major economies in history" (World Bank, 2017). Now, it has become the world's largest economy (in terms of purchasing power parity), manufacturer, machinery merchant, and holder of foreign exchange reserves.

Though China is keeping long-term economic growth, the growth features in different stages differ due to the changes in development policies, and the external environment. In the 21st century, China has experienced three different development stages, and below, we introduce the key features for the different development stages in China that could help understand the structure change of China's economy and what China is undertaking now for the better economic growth.

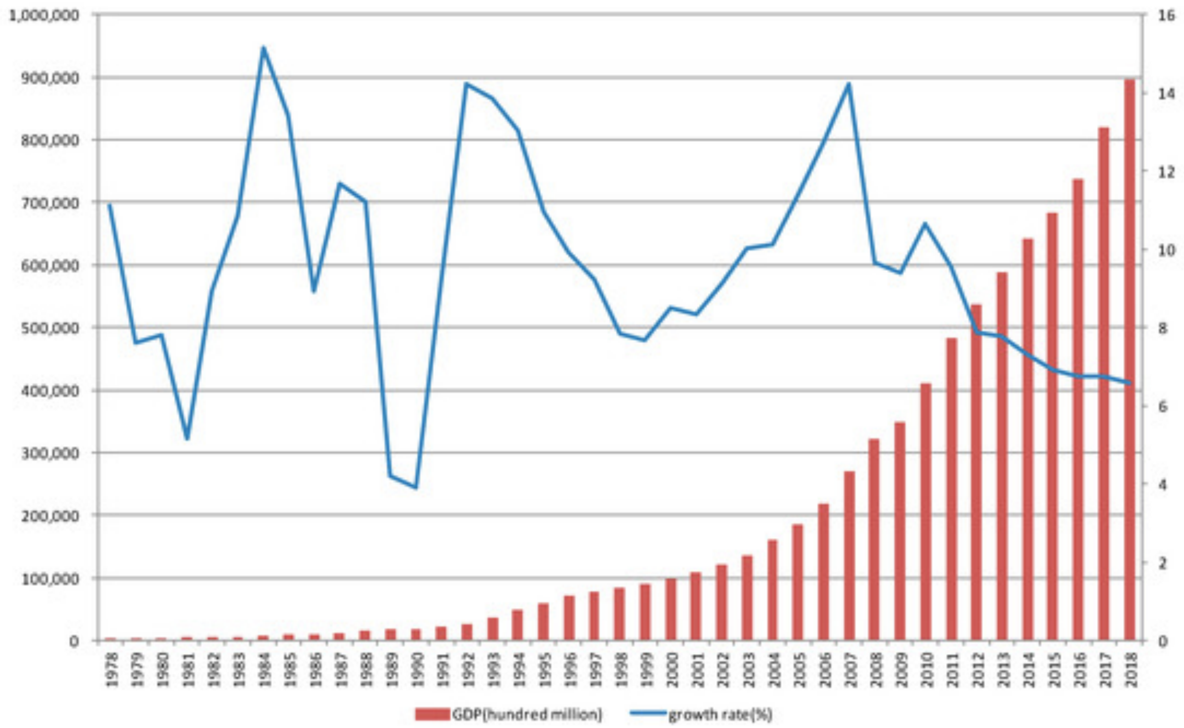

Figure 4 China's GDP and its growth rate from 1978 to 2018. From https://www.mdpi.com/2071-1050/12/3/831/htm

2.1 Precursors to "New Normal"

2.1.1 Before the Financial Crisis (2000-2007)

In 2001, China joined the World Trade Organisation(WTO), it is the most important step during this time period which was a steady step in economic development and gave China better opportunities connecting to the rest of the world (Sterm& Xie, 2020). In the Protocol on The Accession of The People's Republic of China, the government admitted to reduce tariff and open the domestic market for foreign companies. In the meanwhile, it stimulated the Chinese products to enter the world market. As a result China has been deeply involved in the global supply chain and it had great influence on the export and also stimulated foreign investment as well as domestic ones. During that period, the economy growed fast. The average annual GDP growth rate between 2000-2008 was 16.9% and The peak came in 2007 with a growth rate of 23.1%. Part of the reasons for the growth was the development of foreign investment and international trade. Since 1998, China began to have a trade surplus in international trading. In 2004, the surplus was 14 billion dollars and it reached reached a peak of 171 billion dollars in 2008 (OECD, 2012). This growth period which relies on strong export and high investment and focus on heavy manufacturing industy were characterised by the following features:

• Fast economic growth with an average GDP growth rate of 16,9%

• A very high contribution rate of investment to the overall economic growth, with relatively low proportions of expenditure on domestic consumption. (Figure 5)

• An increasing dependence on exports to external markets (Figure 5)

• A very high reliance on the secondary industry especially manufacturing sectors which is energy-intensive and with low technology such as the production of steel and cement.

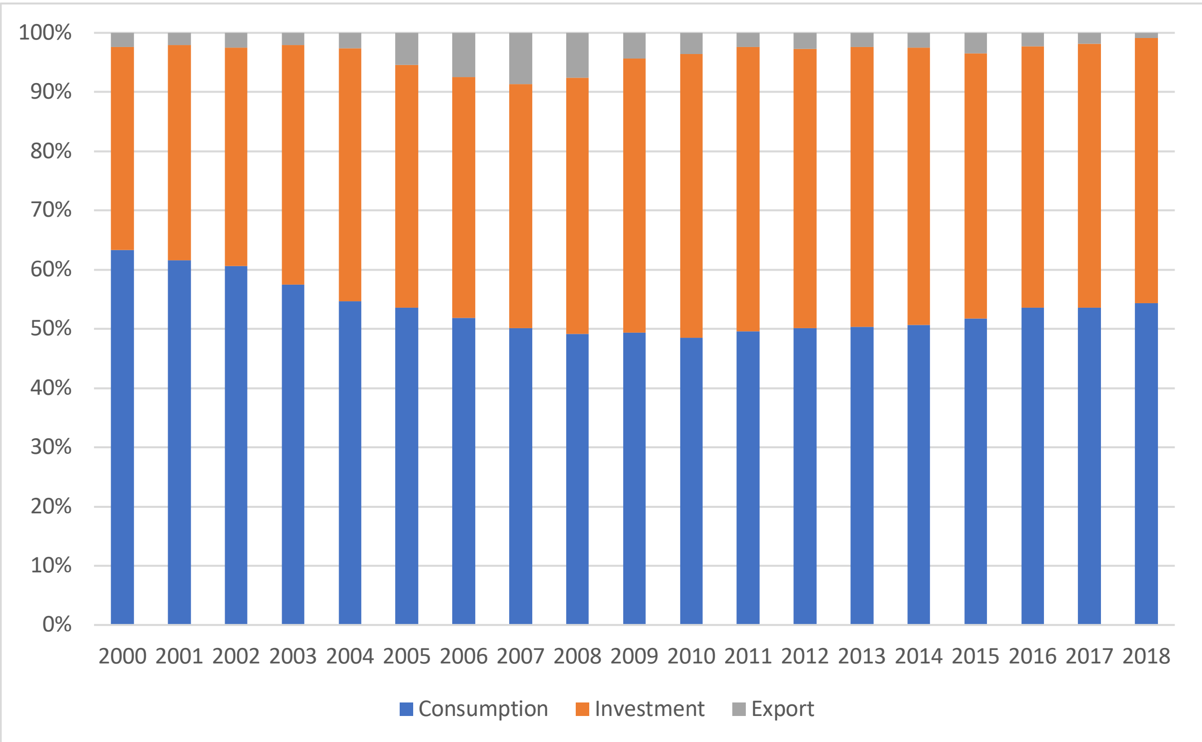

Figure 5 Contribution Rate of Three Components to GDP growth (Source: China's National Statistic Yearbook 2019), Contribution rate= the increase of demand/ the increase of GDP

2.1.2 During the Financial Crisis (2007-2010)

In 2008, the financial crisis caused by the subprime mortgage crisis affected the global financial system and the real economy greatly worldwide. The Chinese economy, as a result of the worsening external environment for exports mainly to the United States and the European Union, suffered a sharp decline in GDP growth rate (Zheng & Tong, 2010). It forced China to turn its economic development reliance on the domestic market. In November 2008, the Chinese government started the " Four Trillion Investment Plan", taking a series of measures to tackle the financial crisis, mainly aiming at stimulating domestic demand, both in terms of consumption and investment. During the 2008 financial crisis, the government invested a lot of money in infrastructure construction, such as building roads, bridges, and providing funds for other public projects to stimulate the economy, promote the economy and keep employment rate. Such policies made investment dominate in the aggregate demand structure (Figure 6).

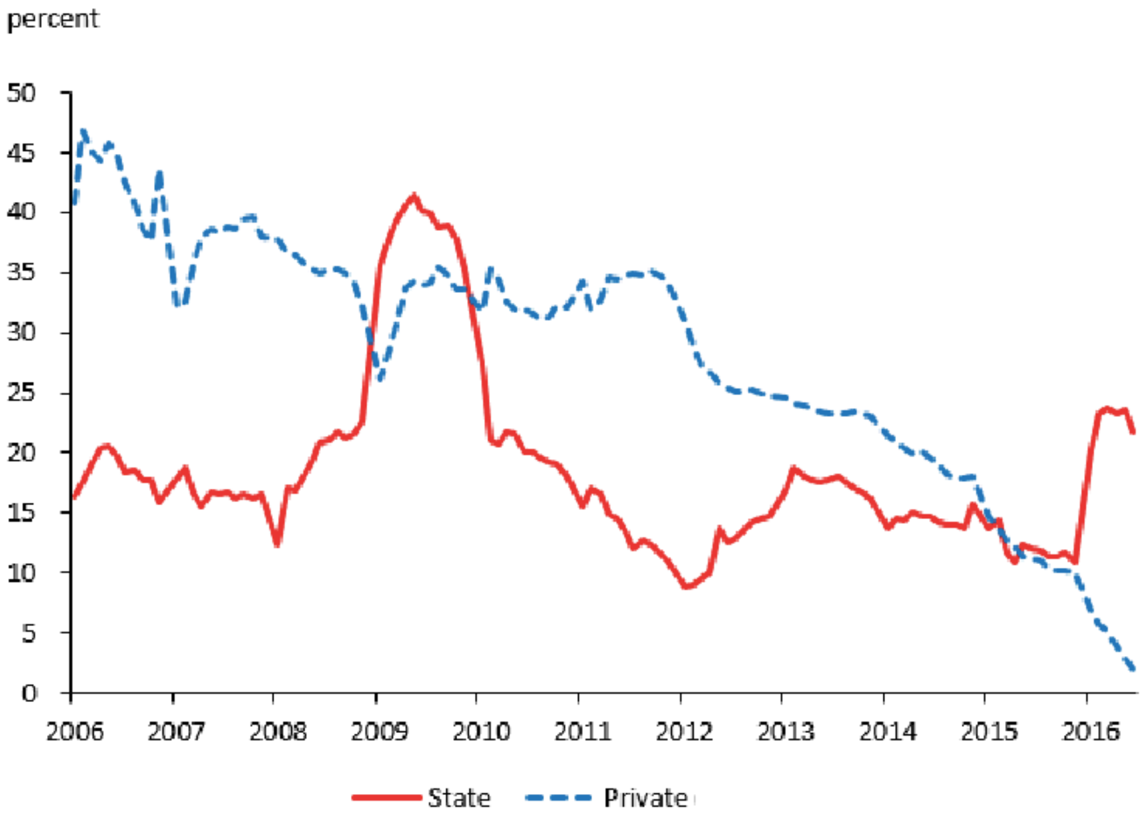

Figure 6 The propotion of public and private investment of China from 2006-2016 (Source: National Bureau of Statistics of China)

Since then, the Chinese government has gradually realized that China's previous economic growth model with the characteristic of "high growth and high emissions" is not environmentally sustainable. The unbalanced production structure which mainly relies on heavy industries and the energy structure dominated by coal has led to severe air pollution and increased smog (CCICED, 2014). It adversely affects people's health and causes social panic. Such unhealthy economic growth also leads to other environmental problems, such as water pollution, water shortages, soil pollution, solid waste, and other forms of ecological degradation (CCICED, 2014). These in turn exacerbate some of the economic and social challenges discussed below. During that stage, China's greenhouse gas emission also increased rapidly(Figure 3).

2.2 New Normal: Structural change, better growth (2010-2014)

After the financial crisis, the Chinese government took a series of measures to stimulate economic recovery, but the measures did not achieve the expected results. China's GDP growth rate has declined sharply from 14.2% in 2007 to 8,2% in 2014. The Monetary Fund (IMF) predicted that the growth rate would continue and drop to 5.5% by 2024 (IMF, 2020). The Chinese government began to realize that the decline in the economic growth rate was not a cyclical slowdown, but a structural one. It means that China has entered a new stage of economic development regardless. In this new stage, a series of new changes will occur. The Chinese government called this stage the "new normal" (Garnaut et al., 2013).

The word “New Normal” was originally proposed by EI Erian to interpret the characteristics of Western developed economies in the quagmire of long-term weakness and high unemployment after the crisis (Melesh, 2017). In China, it is closely related to the stage of economic transformation and development. Chinese government interpreted China's "new normal" as a sustainable development focusing on high-quality growth. Economic growth under the new normal has the following characteristics:

1) Growth rate: An important sign of entering the new normal is the slowdown in the GDP growth rate. From 2000 to 2010, China’s average annual GDP growth rate was 10.5%, and from 2012 to 2014 it dropped to 7.8% (World Bank, 2015). The International Monetary Organization predicts that the average annual growth rate of China's GDP from 2020 to 2030 will remain between 4% and 6%. For emerging economies, high-speed economic growth is unsustainable. A stable and relatively slow economic growth rate is the result of an economy becoming mature.

2) Growth composition: High-quality economic growth is inseparable from economic structural changes. In the new normal phase, China is facing the transformation and upgrading of its industrial structure, and capital allocation has shifted from heavy industries (especially low value-added products such as steel and cement) to service industries and high value-added manufacturing (CCICED, 2014). At the same time, the share of total investment in GDP has decreased, and the share of consumption in GDP has increased. With the development of technology and the improvement of research and development capabilities, China is eager to gain a higher position in the global value chain and play a greater leadership role in various innovative fields including clean energy.

3) Improve energy efficiency: Improving energy efficiency is one of China's development goals after entering the new development stage. The improvement of energy efficiency in China is mainly achieved by improving productivity, developing high-tech technologies, promoting energy-saving products, and expanding the scale of the service industry (Ward et al., 2015). At the same time, due to the reduction in overall energy demand, air pollution and greenhouse gas emissions have also been reduced (Green and Stern, 2014).

These changes in the industrial structure and consumption structure results from the changes in the domestic and international economic environment, and government policies have played a particularly important role in the process. In 2006, the Chinese government set a target to reduce carbon emission per unit of GDP by around 20 percent in the National 12th Five-Year Plan and incorporated relevant indicators into the medium to long-term plans for national economic and social development (National People’s Congress, 2006). In October 2008, the State Council issued the white paper "China's Policies and Actions to Address

Climate Change", which considered that adjusting the economic structure and promoting the optimization and upgrading of the industrial structure is one of the important policies to mitigate climate change (State Council 2008). In 2011, the State Council issued a work plan for greenhouse gas emission control during the "Twelfth Five-Year Plan" period, which requires stricter control of greenhouse gas emissions and strives to reduce CO2 emissions per unit of GDP by 17% by 2015 since 2010 (StateCouncil, 2011). All these measures demonstrate the Chinese government's concern about climate change and its determination to the development low-carbon economy and the establishment of a low-carbon society.

These structural changes are partly due to domestic and international economic changes, and government policies have played a particularly important role in it. In 2006, the Chinese government proposed the goal of reducing energy consumption per unit of GDP by about 20% in the Nation's Eleventh Five-Year Plan, and incorporated relative indicators into the medium- and long-term plan for national economic and social development (NPC, 2006). In October 2008, the State Council released the white paper "China's Policies and Actions for Addressing Climate Change", which considers adjusting economic structure and promoting the optimization and upgrading of the industrial structure as one of the important policies to mitigate climate change (StateCouncil, 2008). In 2011, the State Council released its work plan for reducing greenhouse gas emissions during 2011-2015 (within the 12th Five-Year Plan Period), which requires more strict control of greenhouse gas emissions and aims to reduce carbon intensity in 2015 by 17% from 2010 (StateCouncil, 2011). All of these measures show the Chinese government's concern about climate change and its determination to transition to a low-carbon economy.

The above summary of China's economic structural transformation related to the new development model provides a background for our analysis of China's greenhouse gas emission trends. It is easy to see that every component of China's "new normal" (from lower growth rates to changing energy supplies) has the effect of reducing China's greenhouse gas emissions, whether intentional or unintentional. Therefore, the cumulative mitigation potential associated with the full implementation of the new model may indeed be very large.

The purpose of this study is to analyze the changing trends of China's final demand(export, investment and consumption) and its impact on CO2 emissions after entering the 21st century in order to explore the main driving forces for the growth of carbon dioxide emissions. Therefore, we can provide suggestions and guidance on how to achieve CO2 reduction goals and keep a long-term balance between economic growth and environmental protection under the guidance of New Normal.

Table 2 China's Pledges and Targets(Source:Climate Action Tracker, https://climateactiontracker.org/countries/china/), LULUCF: land use, land use change and forestry

China	*Summary of pledges and targets*	
Paris Agreement	*Ratified*	*Yes*
	2030 unconditional targets	*Peak CO2 emissions latest by 2030* *Non-fossil share of energy supply: 20% in 2030* *Forest stock: +4,5 billion m3 by 2030 compared to 2005* *Carbon intensity: -60% to -65% below 2005 by 2030* *[33-47% above 2010 by 2030 excl, LULUCF for peaking and non-fossil targets]* *[36-53% above 2010 by 2030 excl, LULUCF for carbon intensity targets]*
	Coverage	*Economy-wide*
	LULUCF	*Unclear how LULUCF is included*
Copenhagen Accord	*2020 targets*	*Carbon intensity: -40% to -45% below 2005 by 2020* *Non-fossil share of energy supply: 15% in 2020* *Forest cover: +40 million hectares by 2020 compared to 2005* *Forest stock: +1,3 million m3 by 2020 compared to 2005* *[26% above 2010 by 2020 excl, LULUCF for peaking and non-fossil targets]* *[26-37% above 2010 by 2020 excl, LULUCF for carbon intensity targets]*
	Conditions	*None*
Long-term goals	*Long-term goals*	*None*

3. Research Methods

This Chapter explains the methods and data that are used in this empirical analysis to adress the research objective of this thesis.

3.1 Research Strategies

In order to answer the research questions which were mentioned in the previous section, several research strategies are required. The first two subquestion requires literature research and descriptive analysis as the questions are about finding the relevant relationships. To answer the third and forth subquestion an Import and output analysis and the structure decomposition method should be implemented.

3.2 Data Source

In this research, we use two sets of data: the first one is the input-output table for certain country within a certain time period, and the second one is the corresponding energy consumption data. Input-output data comes from the WIOD database (Timmer, Dietzenbacher & Los, 2015). The WIOD project is sponsored by the European Union and aims to develop databases, accounting tasks, and models that can help understand the trade-off between socio-economic and environmental development on a global scale. It provides the annual world input-output tables of 27 EU countries and 13 other economies since 1995. These tables are constructed based on the national accounts system with a well-defined conceptual framework. In this study, we use China's domestic input-output tables 2000-2014. The original energy consumption data are obtained from Chinese National Energy Statistical Yearbook (National Bureau of Statistics, 2015) and needs further processing.

For literatur review, I choose the web of science(www.webofknowledge.com), google scholar (https://scholar.google.com/) and China National Knowledge Infrastructure (one of the biggest Chinese knowledge resources system which includes journals, doctoral disertations, newspapers, yearbooks, patents and ect. in China, website: http://global.cnki.net/index/) as main database.While reading a lot of relevant literature, it is helpful to sort out the existing hypothesis, research methods, conclusions, and etc which gives a solid foundation for further study. Also, based on the statistical data, it is easy to simply describe the scale and structure of China’s final demand and the main types of commodities.

3.3 Software applied

The Main software used in the study:

1) Microsoft office. Word is used to write the thesis; excel is used to preprocess the data and do simple linear analysis; Plugins such as Endnote, Mathtype and etc. will also be used.

2) R. It is an open sourced programming language that provides computing environment for analyzing and processing data with integrated statistical tools, various mathematical calculations, and statistical functions.

3) Origin, Stata and other software are used to draw the graphs in this study.

3.4 Methods Applied

3.4.1 CO2 Emission Calculation

In this research, we estimated the China's CO2 emissions using the method from IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston, et al., 2006). The energy consumption data is from China Energy Statistical Yearbook (NBSPRC, 2000-2015), and the emission factor is calculated using General Principles of Comprehensive Energy Consumption Calculation (GBT-2589-2008). The equation is as follows:

$$\sum_i C_i = \sum_i \sum_j Conv\ Factor_j \times CC_j \times COF_j \times D_{ij} \tag{1}$$

Where:

C_i is carbon emission in industry i.

D_{ij} is the consumption of energy j in industry I, in detail, D=production+imports-exports-international bunkers-stock change.

$Conv\ Factor_j$ is the conversion factor for energy j to energy units (TJ) on a net calorific value basis.

CC_j is the carbon content (CO_2 emitted per unit heat released) for energy j

$COF_j(carbon\ oxidation\ factor)$ is the fraction of carbon oxidised for energy j. Usually the value is 1, reflecting complete oxidation. Lower values are used only to account for carbon retained idefinitely in ash or soot

$Conv\ Factor \times CC \times COF$ is defined as emission factors and the emission factors for main fules are presented in table S1.

3.4.2 Extended Input-Output Model

The basic Introduction of Input-Output Model

The Input-Output model was proposed by the American economist Wassily Leontief. It is a quantitative economic model that represents the interdependencies between different sectors of a national economy or different regional economies (Leontief, 1951). Leontief began to study the input-output method in the early 1930s. In 1936, he published the article "Quantitative input and output relations in the economic systems of the United States" and in which he made the first input-output table of the United States in 1919 and explained how he collected the data, constructed the model and calculated the result in detail. During World War II, the Input-Output model was used as a scientific and precise method for the US government to witness the interrelationship among the whole economy to strengthen intervention and regulation of macroeconomics. Since then, the US government began to compile national input-output tables regularly, and other countries and institutes also started to prepare such tables.

The input-output method is a comprehensive and systematic analysis of the interrelationship of the production process between the national economy, regional economy, and sectoral economy based on specific economic theory and mathematical models. By compiling the input-output table, the inner connection among various sectors and industries can be revealed clearly; the balance between the production and distribution of each sector and industry, production, and consumption will also be shown (Miller, 2009). This economic entity studied can be as small as a province, a city, or an enterprise sector, but also can be as large as a country or even the entire world. It links the production process with the final demand and is a suitable tool for measuring the pulling effect of the final product.

Environmentally Extended Input-Output Model

The input-output model is a mathematical model used in economics to comprehensively analyze the quantitative dependence between input and output in economic activities within an economy or between multiple economies. It is composed of two parts: the input-output table and the mathematical equations derived from the balanced relationship of the input-output table. The model describes the inputs required by other economic activities and the output or final consumption provided to other activities through economic activities. In most cases, the input-output analysis is the basis for calculating gross domestic product (GDP), which is the market value of all goods and services produced in the economy in a given year.

By integrating information about energy or material use or pollution into the input-output model, an environmentally extended input-output model (EEIOA) can be obtained. EEIOA is increasingly used as a tool to understand material or energy needs or environmental burdens related to a particular sector or final demand component. In the case that the input-output table is extended by material flow, material inputs are allocated to production departments, which can then be linked to the final demand they ultimately meet (Eisenmenger, Wiedenhofer& Schaffartzik, 2014). In this way, a comprehensive economic-energy-environmental relationship can be studied which provides a deeper understanding of carbon emission flows and usage that benefit for further research.

EEIOA is widely used in the energy and environmentally related reseraches. Lin & Polenske (2006) studied China's energy use changes from 1981-1987 and found a significant reduce on energy intensity in this economy. Dias(2014) evaluated the environmental impacts associated with the consumption of goods in Aveiro using EEIOA and found that " food, beverages and tobacco", "construction" and " production, collection and distribution of electricity" were sectors that contributed most to the greenhouse gases emissions. Li and Alsaedi (2015) studied the embodied mercury emissions induced by fossil energy consumtions in Beijing and found that coal combustion takes the major responsibility for energy-related mercury emissions.

Fundamentals and Notions of Input-Output Analysis

The basic format of the model is an inter-industry matrix where colunm entries represent inputs of an industrial sector and row entries represent outputs from a given sector. Each column of the input–output matrix represents the composition of inputs required to produce each output and each row represents the distribution of each sector's outputs. And for the input part, the domestic input and import can be seperated. As the input-output model is linear in nature, it is easy to access to rapid computation which has made it a tool being extensively used for economic analysis at various levels from domestic to international (Miller and Blair, 2009). The following table shows the format of the input-output table.

Table 3 Format of Environmental Extended Input-output table

		Producers as consumers	Final Demand				Import	Total Output
		1,2,…,n	Consumption	Investment	Export	Total		
Domestic producers	1 2 … n	x_{ij}^d	c_i^d	in_i^d	ex_i^d	Y_i^d		X_i
Import producers	1 2 ... n	x_{ij}^m	c_i^m	in_i^m	ex_i^m	Y_i^m	M_i	
Value added		V_j						
Carbon Emission		B_j						
Total input		X_j						

In this table, the producer-consumer part records the consumption of a specific product j to the production of another product i; the final demand part records the final destination of output, such as investment, consumption and export. The value-added component includes all non-industrial inputs used druing the producing process within economic activities, such as capital, labor, depreciation of fixed assets, taxes, and etc. (Miller and Blair, 2009).

Assume that there is an economy with n sectors. Each sector produces x_i unit of good,thus x_{ij} units from j sector need to be used. Supplementary to this inter-industry demands there are some exogenous demands created by consumption, investment and exports as c_i, in_i and ex_i . Those demand are referred to as final demand as they are for goods to be used and not as an input for another process in a sector. A simple equation that can be formulated.
Let

$$Y_i^d = c_i^d + in_i^d + ex_i^d \tag{1}$$

Then for domestic input, the equation is

$$X_i = x_{i1}^d + x_{i2}^d \cdots + x_{in}^d + Y_i^d \tag{2}$$

As there are n sectors in the input-output table, equation (2) can be extened as following:

$$
\begin{aligned}
&X_1 = x^d_{11} + x^d_{12} \cdots + x^d_{1n} + Y^d_1 \\
&\vdots \\
&X_i = x^d_{i1} + x^d_{i2} \cdots + x^d_{in} + Y^d_i \\
&\vdots \\
&X_n = x^d_{n1} + x^d_{n2} \cdots + x^d_{nn} + Y^d_n
\end{aligned} \tag{3}
$$

Set the direct consumption coefficient of domestic products a^d_{ij}

$$
a^d_{ij} = \frac{x^d_{ij}}{X_j} (i = 1, 2, \cdots, n; j = 1, 2, \cdots, n) \tag{4}
$$

Equation(3) is equal to the following:

$$
\begin{aligned}
&X_1 = \frac{x^d_{11}}{X_1} X_1 + \frac{x^d_{12}}{X_2} X_2 \cdots + \frac{x^d_{1n}}{X_n} X_n + Y^d_1 \\
&\vdots \\
&X_i = \frac{x^d_{i1}}{X_1} X_1 + \frac{x^d_{i2}}{X_2} X_2 \cdots + \frac{x^d_{in}}{X_n} X_n + Y^d_i \\
&\vdots \\
&X_n = \frac{x^d_{n1}}{X_1} X_1 + \frac{x^d_{n2}}{X_2} X_2 \cdots + \frac{x^d_{nn}}{X_n} X_n + Y^d_n
\end{aligned} \tag{5}
$$

Thus, equation (5) can be written as:

$$
\begin{aligned}
&X_1 = a^d_{11} X_1 + a^d_{12} X_2 \cdots + a^d_{1n} X_n + Y^d_1 \\
&\vdots \\
&X_i = a^d_{i1} X_1 + a^d_{i2} X_2 \cdots + a^d_{in} X_n + Y^d_i \\
&\vdots \\
&X_n = a^d_{n1} X_1 + a^d_{n2} X_2 \cdots + a^d_{n2} X_n + Y^d_n
\end{aligned} \tag{6}
$$

Thus

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} a_{11}^d & a_{12}^d & \cdots & a_{1n}^d \\ a_{21}^d & a_{22}^d & \cdots & a_{2n}^d \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1}^d & a_{n2}^d & \cdots & a_{nn}^d \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} + \begin{bmatrix} Y_1^d \\ Y_2^d \\ \vdots \\ Y_n^d \end{bmatrix} \tag{7}$$

Let

$$, \quad A^d = \begin{bmatrix} a_{11}^d & a_{12}^d & \cdots & a_{1n}^d \\ a_{21}^d & a_{22}^d & \cdots & a_{2n}^d \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1}^d & a_{n2}^d & \cdots & a_{nn}^d \end{bmatrix}, \quad Y^d = \begin{bmatrix} y_1^d \\ y_2^d \\ \vdots \\ y_n^d \end{bmatrix}, \quad X = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix}$$

Then,

$$X = A^d X + Y^d \tag{8}$$

Based on the mathematical defination , equation (8) is the same as the following:

$$X = \left(I - A^d\right)^{-1} Y^d \tag{9}$$

Where,

$$(I - A^d) = \begin{bmatrix} (1-a_{11}^d) & -a_{12}^d & \cdots & -a_{1n}^d \\ -a_{21}^d & (1-a_{22}^d) & \cdots & -a_{2n}^d \\ \vdots & \vdots & \ddots & \vdots \\ -a_{n1}^d & -a_{n2}^d & \cdots & (1-a_{nn}^d) \end{bmatrix} \tag{10}$$

$L = \left(I - A\right)^{-1}$ is called the Leontief inverse matrix, thus

$$X = L^d Y^d \tag{11}$$

Define f_j as te carbon intensity for department j,

$$f_j = \frac{b_j}{X_j} \tag{12}$$

When b_j is the direct carbon emission of department j and X_j is the total output of department j. complete carbon emission CF can be written as:

$$CF = FX = FL^d Y^d \tag{13}$$

Decompose equation(13) to government consumption, investment and export, the equation is as follows:

$$CF = FL^d Y_c^d + FL^d Y_{in}^d + FL^d Y_{ex}^d \tag{14}$$

Define the value-added generated by a unit input in department j as r_j,

$$r_j = \frac{V_j}{X_j} \tag{15}$$

$R = (\ r_1, \ \ r_2, \ \ \cdots \ \ r_n)$,GDP is the sum of the added value of each sector,

$$GDP = RX = RL^d Y^d \tag{16}$$

Acoordingly, the equation can be decomposed as the following:

$$\begin{aligned} GDP &= RL^d Y_c^d + RL^d Y_{in}^d + RL^d Y_{ex}^d \\ &= GDP_c + GDP_{in} + GDP_{ex} \end{aligned} \tag{17}$$

Thus we can have the total carbon emission intensity CIF, the carbon emission intensity of consumption CIF_c, investment CIF_{in} and export CIF_{ex} as follwing:

$$\begin{aligned} CIF &= \frac{CF}{GDP} = \frac{PL^d Y^d}{RL^d Y^d} \\ CIF_c &= \frac{CF_c}{GDP_c} = \frac{PL^d Y_c^d}{RL^d Y_c^d} \\ CIF_{in} &= \frac{CF_{in}}{GDP_{in}} = \frac{PL^d Y_{in}^d}{RL^d Y_{in}^d} \\ CIF_{ex} &= \frac{CF_{ex}}{GDP_{ex}} = \frac{PL^d Y_{ex}^d}{RL^d Y_{ex}^d} \end{aligned} \tag{18}$$

Using the formulas above, we can see the interrelationship between final demand, carbon emissions and economic growth.

Data acquisition and processing

To start the EEIOA analysis, two sets of data are required, they are the input and output tables and the corresponding energy consumption data from 2000 to 2014. Due to the restriction of statistical calibers, the data needs to be further adjusted.

This study uses global single-region non-competitive input-output tables obtained from the WIOD database. Originally the tables have 46 sectors, and this paper aggregates all tables into 16 sectors (Table 4). The sector aggregation is based on the Classification and Code Standard of National Economy Industry Standard GB/T 4754-2002 (NBSPRC, 2002), which is consistent with the CO2 emission sector classification.

Table 4 Sector aggregation for input-output table

No.	Input-Output Sector	Code	Description
1	Agriculture	A01	Animal and crop husbandry; hunting and other related activities
		A02	Forest industry and felling
		A03	Fishery industry and aquaculture
2	Mining	B	Mining industry; quarrying industry
3	Food and Tobacco	C10-C12	Manufacture of beverages, foodstuff and tobacco products
4	Textiles	C13-C15	Manufacture of textiles, clothing and leather products
5	Paper and printing	C17	Paper and allied industries
		C18	Printing and duplication of recorded media
6	Petroleum and Coking	C19	Manufacture of coke and refined petroleum products
7	Chemicals	C20	Chemical raw materials and chemical products manufacturing
		C21	Production of essential drug products and pharmaceutical preparations
		C22	Production of rubber products and plastics
8	Non-metallic mineral products	C23	Production of other non-metallic minerals and products
9	Metal Products	C24	Production of basic metals
		C25	Production of metalwork, except machinery and equipment
10	Machichinery	C26	Production of computer, electronic and optical products
		C27	Production of electrical equipment
		C28	Production of machinery and equipment n.e.c.
		C29	Production of automobile, trail cars and semi-trailers
		C30	Production of other transport equipment
11		C31_C32	Production of furniture; other manufacturing

	Other Manufacturing	C16	Production of wood and other woodwork, except furniture; production of straw and woven products
		E37-E39	Garbage collection, disposal, and recycling; materials recovery; remediation activities and other trash management services
		C33	Repair and installation of machinery and equipment
12	Electricity, gas, water	D35	Electricity, gas, steam and air conditioning supply
		E36	Water collection, treatment and supply
13	Construction	F	Construction
14	Wholesale and retail	G45	Wholesale and retail business of automotive vehicles and motorbikes
		G46	Wholesale business, except of automotive vehicles and motorbikes
		G47	Retail business, except of automotive vehicles and motorbikes
15	Transport	H49	Land and pipeline transportation
		H50	Water transportation
		H51	Air transportation
		H52	Warehousing and other supporting services for transportation
		H53	Postal and express services
16	Other Services	I	Hotels and catering services
		J58	Publishing industry
		J59_J60	Production of film, video and TV program, recording and music publishing activities; show and radio broadcasting
		J61	Telecommunications
		J62_J63	Computer programing; consultancy and its supporting activities; information service
		K64	Financial services, except insurance and pension funding
		K65	Insurance, reinsurance and pension funding, except social welfare security
		K66	Activities subordinate to the industry of finance and insurance
		L68	Real estate activities
		M69_M70	Legal and accounting activities; activities of head offices; management consultancy activities
		M71	Architectural and engineering activities; technical testing and analysis
		M72	Scientific research
		M73	Marketing research and advertising
		M74_M75	Other scientific, professional and technical activities
		N	Administrative and supporting service
		O84	Public administration; national defence; social welfare security

		P85	Education
		Q	Health industry and other related social activities
		R_S	Other service activities

Since the WIOD input-output table is based on the current price, in order to make comparisons, this paper adjusts the current price table to a constant price table through the price index using the year 2000 as the price base year (table 5). The constant price for a specific sector is the original price divided by the corresponding price index.

Table 5 Price Index used in different sectors (Source: China statistical yearbook, 2000-2014)

Sector	Category	Price Index
Agriculture	Agriculture	Producer Price Indices for Farm Products
Mining	Secondary Sectors	Ex-Factory Price Indices of Industrial Products by Sector
Food and Tobacco		
Textiles		
Paper and printing		
Petroleum and Coking		
Chemicals		
nonmetallic mineral products		
Metal Products		
Machichinery		
Other Manufacturing		
Electricity, gas, water		
Construction	Construction	Price Indices of Investment in Fixed Assets
Wholesale and retail	Wholesale and retail	National Retail Indices
Transport	Transport	Consumer Price Indices by category
Other Services	Other Services	National Consumer Price Indices

Thus we can get a comparable input-output table.

The energy consumption for each sector is obtained from the China Energy Statistical Yearbook (National Bureau of Statistics, 2000-2015). The first step is to integrate the table into 16 sectors the same as the input-output table (table 4). The CO2 emission can be calculated as 3.4.1 described.

3.4.3 Structural Decomposition Analysis (SDA)

The basic Introduction of SDA Model

The structural decomposition analysis(SDA) is a widely used technique in decomposition analysis especially in the study of the driving force of energy-related carbon emissions. The SDA model is based on the input-output data and is used to disaggregate the total changes of the output to several components. For example, to compute the effects of changes in final demand, and energy efficiency on the total change of carbon emission intensity last year. The SDA model provides users a tool to quantify fundamental drivers for changes and is defined as “the analysis of the economic change by means of a set of comparative static changes in key parameters in an input-output table” (Rose& Chen, 1991). Leontief and Ford (1972) were the ones who first introduced the method in energy-related researches and afterward it has been widely used in the fields of environment and energy (Lan et al., 2016). This method can be used to evaluate the most important drivers of energy consumption changes in a country and find the contribution rate for each drivers. For example, SDA has been used to estimate the drivers of carbon emission changes in the U.S. during 1972–1982 (Casler & Rose, 1998), in Japan during 1975-1995 (Han & Lakshmanan, 1994), in Taiwan during 1981–1991 (Chang & Lin, 1998), the in Denmark during 1966–1988 (Wier, 1998), and in Korea during 2003-2011 (Kim, Yoo &Oh, 2015).

The SDA method is also widely used in the study of China’s energy consumption and carbon emissions. Andreosso-O'Callaghan & Yue (2002) used the IO-SDA method to evaluate the effects of technology, economic structure and lifestyle to the carbon emissions during 1987-1997 which shows that The impact of China's infrastructure construction and urban household consumption on carbon dioxide emissions exceeds the impact of improved energy efficiency on carbon dioxide emissions. Zhang (2009) used the SDA method to decompose the energy carbon dioxide intensity from 1992 to 2006. The results showed that during the study period, the intensity of energy-related carbon dioxide decreased by about three-quarters, which was mainly caused by changes in production patterns. On the other hand, changes in demand patterns have pushed up carbon emission intensity. Chang & Tanikawa (2013) used the IO-SDA method to analyze the trends of carbon dioxide emissions in Beijing from 1998 to 2007. Empirical research results showed that the final demand and industrial structure changes had the most significant impact on carbon dioxide emissions.

Based on the most recently released energy data and input-output tables, this paper uses SDA and EEIOA methods to evaluate the driving factors of China’s carbon emission changes from 2000 to 2014. The influence of the 2008 financial crisis as well as the new normal policy are concerned.

The Driving Factors of Carbon Emissions

As we discussed above, the human activities have significant influence on the environment. Ehrilich&Holden (1971) proposed the IPAT model which revealed the impact of human activities on the environment. The equation is expressed as follows:

$$I = P \bullet A \bullet T \tag{19}$$

In this equation, I represents the environmental impacts, which is expressed as actual pollutant emissions; P represents the country’s total population; A represents the country’s affluence, which is usually expressed as per capita GDP; T represents the country technical level, which is expressed as emission intensity.

Waggoner&Ausubel (2002) renovated the “IPAT identity” to identify actors with force and established a new model:

$$I = P \bullet A \bullet C \bullet T \tag{20}$$

Where I represents the environmental impacts; P represents the country's total population; A represents the consumption volume, which is expressed as GDP per capita; C represents the intensity of use, which is expressed as energy per GDP; T represents the ratio of environmental impact to good demanded by people and produced.

IPAT is a simple model that shows the relationship between the main driving forces and the environment changes. The model shows that all the driving forces work together to influence the environment. For example, if the level of affluence increases while the total population and technology level of a country remain unchanged, the increase of the pollutant level can't be attributed to the rise of affluence alone. Even if the technology level and total population are fixed, they work as multiple in the equation. This model also has disadvantages. First, it can only assess the direct impact of these drivers on the environment. Second, the model is integrated, so it is not easy to define which industry or which demand component contributed most to the total environmental changes. This problem can be solved by combining input-output model with IPAT model as input-output model can provide more dimensions.

This study combines the environmental input and output with the IPAT model to decompose CO2 emissions into five driving factors: population, carbon emission intensity, economic production structure, final demand structure and per capita GDP (Guan et.al,. 2008), and establishes the following model:

$$CF = pFLY_sY_v \tag{21}$$

Where CF is the total carbon dioxide emissions; p is the population size; F is a line vector representing the direct carbon emission intensity of each sector, L is the Leontief inverse matrix $L = (I - A)^{-1}$, Y_s reparesents the consumption structure. Y_v is the per capita consumption volume(per capita consumption volume equals per capita GDP). Then use the SDA method to decompose the factors.

Fundamentals and Notions of SDA

Take the basic input-output model for example: $X = BY$, where X represents the total output vector, B represents the Leontief inverse matrix, and Y represents the final demand vector. Set 0 as the base year and t as and the comparative year. Then the changes of the total final output X can be decomposed using the following equation:

$$\begin{aligned} X_t - X_0 &= B_tY_t - B_0Y_0 \\ &= (B_t - B_0)Y_0 + B_0(Y_t - Y_0) + (B_t - B_0)(Y_t - Y_0) \end{aligned} \tag{22}$$

While $(B_t - B_0)Y_0$, $B_0(Y_t - Y_0)$ and $(B_t - B_0)(Y_t - Y_0)$ represent the effect of changes in the intermediate inputs,in final demand and the interactions.

The form of structural decomposition is not unique. For example, if a variable is determined by n factors, then there will be n! forms of decomposition (Dietzenbacher& Los, 2006). In this study, we choose a bipolar decomposition method (Li, 2004). The main idea of this method is to calculate the arithmetic mean value of two periods, and this is:

$$X_t - X_0 = (B_t - B_0)Y_t + B_0(Y_t - Y_0) \text{ or } X_t - X_0 = (B_t - B_0)Y_0 + B_t(Y_t - Y_0)$$

These two decomposed results differ due to the selection of different base year. By using the bipolar decomposition method, we can get that:

$$X_t - X_0 = \frac{1}{2}(B_t - B_0)(Y_0 + Y_t) + \frac{1}{2}(B_t + B_0)(Y_t - Y_0) \tag{23}$$

Using the same method, we decompose equation (21) as following:

$$\Delta CF = \Delta pFLY_sY_v + p\Delta FLY_sY_v + pF\Delta LY_sY_v + pFL\Delta Y_sY_v + pFLY_s\Delta Y_v \tag{24}$$

where Δ represents the changes in a factor; CF is the total carbon dioxide emissions; p is the population size; F is a line vector representing the direct carbon emission intensity of each sector, L is the Leontief inverse matrix $L = (I - A)^{-1}$, Y_s reparesents the consumption structure. Y_v is the per GDP.

Therefore

$$\Delta CF = \Delta pF_tL_tY_{s_t}Y_{v_t} + p_0\Delta FL_tY_{s_t}Y_{v_t} + p_0F_0\Delta LY_{s_t}Y_{v_t} + p_0F_0L_0\Delta Y_sY_{v_t} + p_0F_0L_0Y_{s_0}\Delta Y_v$$

Or

$$\Delta CF = \Delta pF_0L_0Y_{s_0}Y_{v_0} + p_t\Delta FL_0Y_{s_0}Y_{v_0} + p_tF_t\Delta LY_{s_0}Y_{v_0} + p_tF_tL_t\Delta Y_sY_{v_0} + p_tF_tL_tY_{s_t}\Delta Y_v$$

Then use bipolar decomposition method, we can get

$$\begin{aligned}\Delta CF &= \frac{1}{2}\Delta p(F_tL_tY_{s_t}Y_{v_t} + F_0L_0Y_{s_0}Y_{v_0}) + \frac{1}{2}\Delta F(p_0L_tY_{s_t}Y_{v_t t} + p_tL_0Y_{s_0}Y_{v_0}) \\ &+ \frac{1}{2}\Delta L(p_0F_0Y_{s_t}Y_{v_t} + p_tF_tY_{s_0}Y_{v_0}) + \frac{1}{2}\Delta Y_s(p_0F_0L_0Y_{v_t} + p_tF_tL_tY_{v_0}) \\ &+ \frac{1}{2}\Delta Y_v(p_0F_0L_0Y_{s_0} + p_tF_tL_tY_{s_t})\end{aligned} \tag{25}$$

Table 6 The decompisition result for different drivers

Decomposition Factor	Decomposition Result
population	$\frac{1}{2}\Delta p(F_tL_tY_{s_t}Y_{v_t} + F_0L_0Y_{s_0}Y_{v_0})$
Carbon intensity	$\frac{1}{2}\Delta F(p_0L_tY_{s_t}Y_{v_t t} + p_tL_0Y_{s_0}Y_{v_0})$
Production structure	$\frac{1}{2}\Delta L(p_0F_0Y_{s_t}Y_{v_t} + p_tF_tY_{s_0}Y_{v_0})$

Consumption structure	$\frac{1}{2}\Delta Y_s(p_0F_0L_0Y_{v_t}+p_tF_tL_tY_{v_0})$
Consumption volume	$\frac{1}{2}\Delta Y_v(p_0F_0L_0Y_{s_0}+p_tF_tL_tY_{s_t})$

The decomposition result for each decomposition factor reflects the impact of changes in carbon emission of a specific influencing factor when other factors remain unchanged. If the effect value is negative, it indicates that the influencing factor is promoting the decrease of the carbon emission, and if the effect value is positive, it indicates that the influencing factor is inhibiting the decrease of the carbon emission. The analysis result will answer the question of what is the most significant factor influencing the CO2 emissions overall and for each final demand perspective. And it is meaningful for further study on how to reduce carbon emission.

Through the same method, we can also conduct SDA decomposition on government consumption, household consumption, investment, and export.

Data acquisition and processing

Based on the SDA model constructed above, we use R studio as a processing tool to analyze the contribution of five driving factors to the increase in CO2 emissions in the different periods. To facilitate the subsequent analysis, we firstly adjust the original data and the description is as below.

Population (p) is the numerical value from China statistical yearbook 2015. The data for the year 2000 and 2010 are the census year estimates; the rest of the data have been estimated on the basis of the annual national sample surveys of population.

Carbon intensity (F) is the CO2 emission per unit of output and it is a 16-dimensional row vector.

Production structure (L) is a 16×16 Leontief inverse matrix that has already been used in the input-output analysis. The transfer between input and output among different sectors presents the production structure of the economic system.

Consumption structure(Y_s) is a 16-dimensional column vector that represents the distribution of each sector in total consumption. The consumption structure for consumption (government consumption and household consumption), investment, and export can also be used in calculating the influencing factors of each final demand perspercitive.

Consumption volume(Y_v) is the numerical value. It is the constant-price GDP each year divided by the population of that year. In China statistical yearbook, eight constant-price base periods have been applied, they are 1952, 1957, 1970, 1980, 1990, 2000, 2005, 2010 and the current base period is 2010. In this study, we choose 2000 as the base period so the constant-price GDP need to be recalculated using different GDP Deflator. The equation is as following:

$$\text{constant-price } GDP = \frac{GDP}{GDP \text{ Deflator}} \tag{26}$$

Thus we can get the constant price GDP using the price base year 2000. Y_v then can be calculated.

Table 7 constant price GDP using the price base year 2020 (trillion $), author's calculation

Year	Constant Pirce GDP	Constant Pirce GDP (price base year=2000)
	Price base year= 2000	
2000	1,21	1,21
2001	1,31	1,31
2002	1,43	1,43
2003	1,58	1,58
2004	1,74	1,74
2005	1,95	1,95
	Price base year= 2005	
2006	2,65	2,26
2007	3,17	2,71
2008	3,81	3,25
2009	4,24	3,62
2010	4,73	4,04
	Price base year= 2010	
2011	7,00	4,64
2012	7,73	5,12
2013	8,49	5,62
2014	9,18	6,08

4. Analysis Results

4.1 Total CO2 Emissions in China

From 2000 to 2014, China's carbon emissions increased from 3376 Mt to 9946 Mt, with an average increase rate of 13,9%. Carbon emissions increased rapidly from 2000 to 2008, and the growth rate slowed down slightly from 2008 to 2010. After 2010, the carbon emission growth rate dropped sharply, and around 2014, the rate was close to zero. Figure 7 shows the CO2 emission data estimated in this paper and compares it with the emission data from International Energy Agency (IEA) and Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Oak Ridge National Laboratory (CDIAC).

As is displayed in figure 7, the carbon emission data from various agencies are relatively close, especially the estimated data and IEA ones, which shows that the calculating process and results are acceptable. The reason why the data from CDIAC is higher than the other two is that the database includes CO2 emissions both from fossil fuels and cement production.

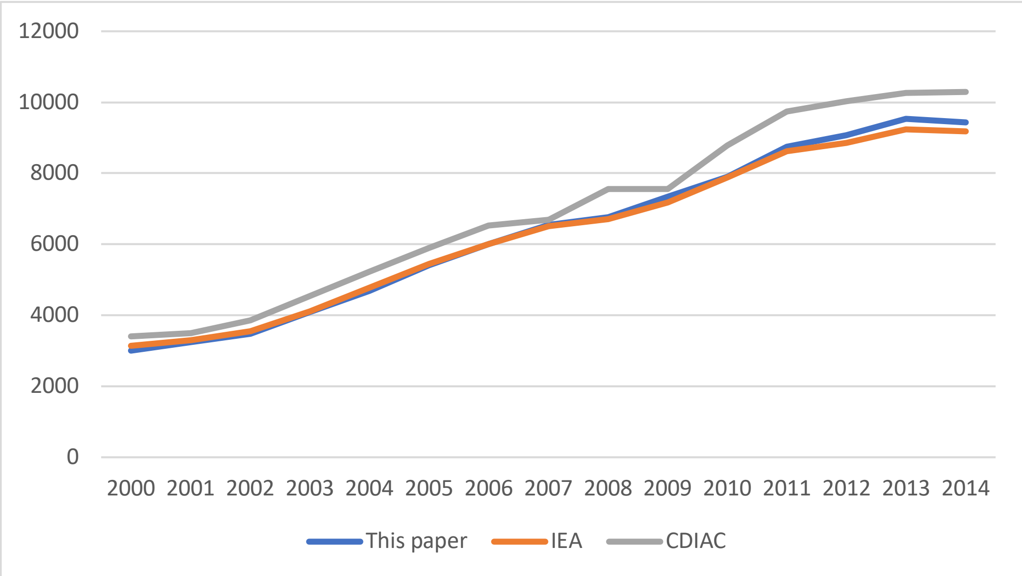

Figure 7 Comparison of China's carbon emissions by different institutions 2000-2014(Mt); (Souce: This Paper: author's calculation; IEA: https://www.iea.org/data-and-statistics?country=CHINAREG&fuel=CO2%20emissions&indicator=CO2%20emissions%20by%20energy%20source; CDIAC: https://cdiac.ess-dive.lbl.gov/trends/emis/tre_coun.html)

China is the largest coal producer in the world (Zhang et al., 2012), and coal plays a dominant role in China's energy structure (Figure 8). In 2000, CO2 produced by coal consumption (raw coal, cleaned coal, washed coal, and briquettes) accounted for 62,07% of the total emissions, which far exceeded the world average. As the table S1 shown, the CO2 emission factor of coal is small while the emission factor of natural gas is large. It means that under the same amount of energy consumption, the consumption of coal will produce the most carbon dioxide. Therefore, China's energy structure with a high proportion of coal leads to a large amount of carbon dioxide emissions. In 2014, the proportion of coal consumption dropped to 56.9%, while the share of clean energy such as hydropower, wind, and solar energy has increased. It indicates that in recent years, China's coal-based energy consumption structure has changed, but the unbalanced energy consumption structure is difficult to improve thoroughly in the short term. The phenomenon of over-reliance on cheap coal with large stores still exists. The economic development model that relies too much on energy resources has not changed significantly.

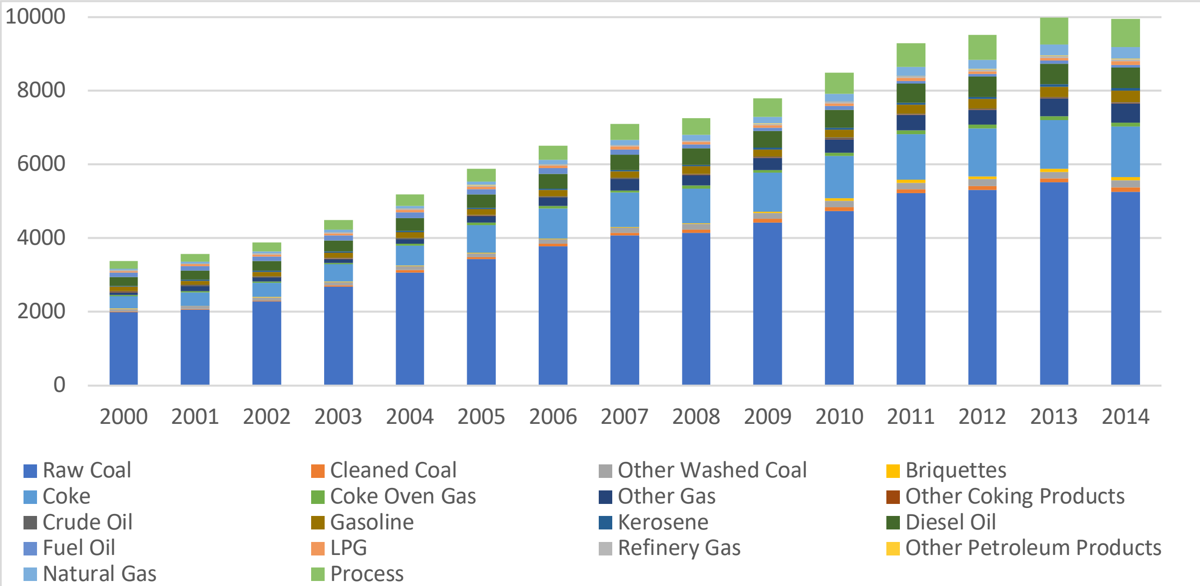

Figure 8 Carbon Emission by energy commodities in China from 2000-2014 (Mt), author's calculation

Figure 9 shows the carbon emissions by industry. The carbon emissions for different industries are significantly different. Among all industries, the carbon dioxide emitted by electricity, gas, and water supply took the largest share of total carbon emissions, which was more than 40%. The second-largest emission industry is non-metallic mineral products, which accounted for more than 15% of the total emission. The CO2 produced by the primary and tertiary industries accounted for 2% to 3% of the total emission. And the proportion for each industry didn't change much between 2000-2014.

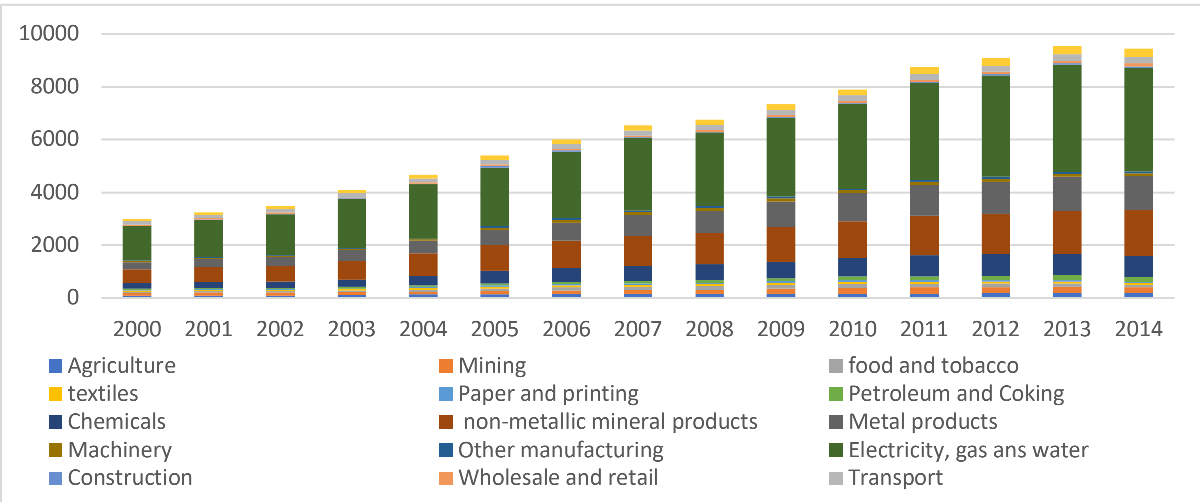

Figure 9 Carbon Emission by industry in China from 2000-2014 (Mt), author's calculation

4.2 The Economic growth and CO2 Emissions Changes from Demand Perspective

Figure 10 illustrates the constant-price GDP between 2000-2014 by different final use categories. In 2000, the constant-price GDP was \$1,21 trillion, and in 2014, it rose to \$6,08 trillion, which is about five times of that in 2000. Generally speaking, Generally speaking, China's GDP has kept uninterrupted and stable growth, and the categories-consumption, investment, and exports also had the same growth trend. It might because consumption, investment, and exports are all main components of the national economy, and they are inseparably connected with the national economy. In years of rapid economic growth, they grow fast and vice versa. And within a certain economic period, the performance of each demand also differs.

From 2000-2007, China's GDP increased rapidly, with a growing increase rate of 16,7% on average. Among the three final demands, the increase in export contributed the most with an average growth rate of 24,1%, then followed by an investment of 18,73%. The average growth rate of GDP in consumption was 12,33%. The growing differences result in the changes in the final demand structure in China. In 2000, the consumption created more than half of the GDP but the proportion decreased from 2000-2007. The proportion of export increased and reached the top at around 2007. The proportion of investment didn't change much at that time (Figure 11).

During 2007-2010 the economy didn't grow as smoothly as before. In 2009, the increased rate of GDP decreased sharply from 19,9% (2008) to 11,4%, which was a reflection of the 2008 financial crisis. Among the three demand perspective, the export was affected the most with a decrease of 11,23% in 2009. The increase in investment of 26,25% offset the adverse effect of export to some degree. As a result, the proportion of investment increased while it for export decreased in demand structure (Figure 11).

After the financial crisis, the growth rate of GDP recovered in 2011 but the growth speed slowed down afterward. As discussed above, it showed that China has been entering the stage of "New Normal" which requires a slower but more sustainable economic development. As for the demand structure, the proportion of consumption increased while it for export further decreased, which indicates a change from the export-driven economy to domestic demand-driven, especially the consumption-driven economy (Figure 11).

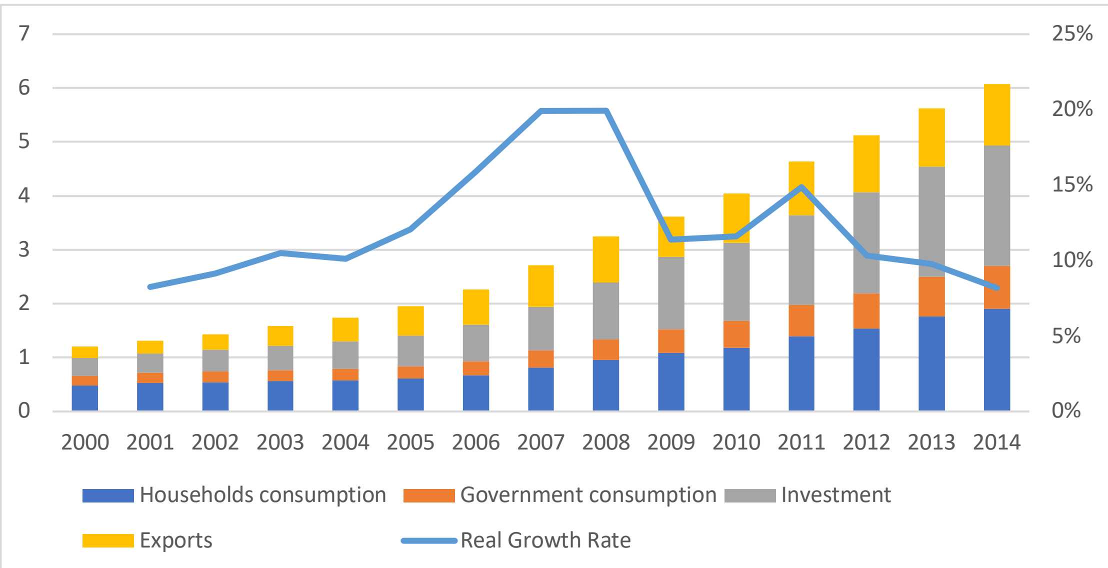

Figure 10 Constant-price GDP ($trillion) and real growth rate(%) from demand side from 2000-2014, author's calculation

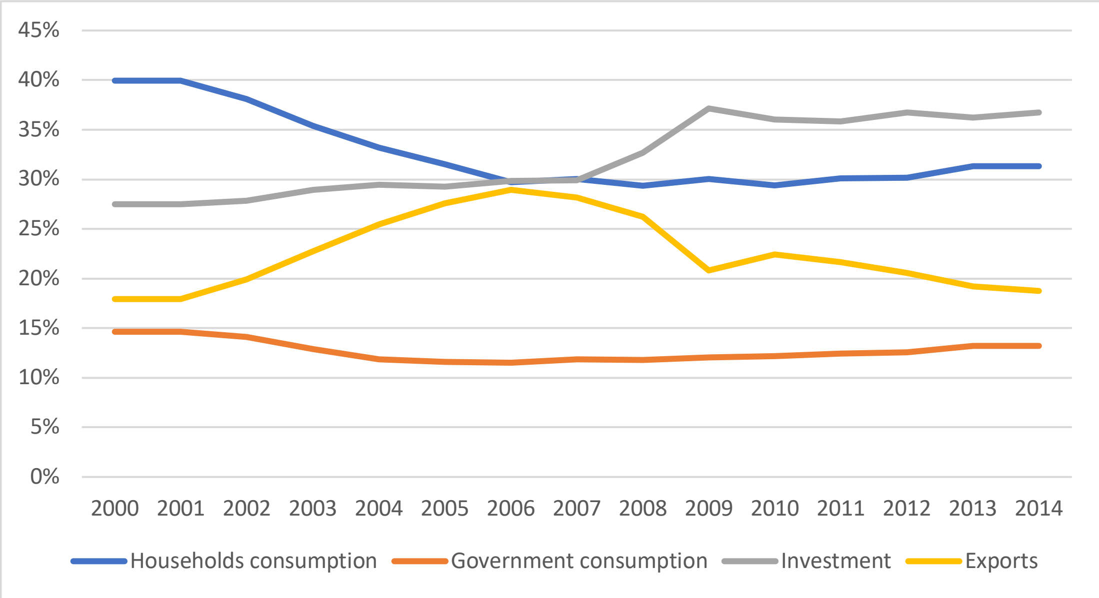

Figure 11 The percentage of GDP for each component of final demand, author's calculation

The final demand contributed to the increase in the total CO2 emissions. From 2000-2014, China's carbon emission had increased from 3325Mt to 9410Mt, with an increasing rate of 13,1% on average. During the same period, China's GDP increased by five times, showing that China's rapid economic development is an important reason for the rapid increase in carbon emissions. The carbon emission for household consumption, government consumption, investment and export increased by 80,4%, 124,4%, 292,4% and 216,9% respectively. The increase rate of consumption was lower than the total increase rate while the increase rate of investment and export was higher than the increase rate of the total consumption. The different growing speeds resulted in a change in the proportion of carbon emissions for different demands. In 2000, half of the carbon emissions produced was because of consumption, but in 2014, the only 30% of the total emission was for consumption purpose (Figure 13). The proportion of investment increased from 33% to 46%, which was the main driver for the increase in carbon emission.

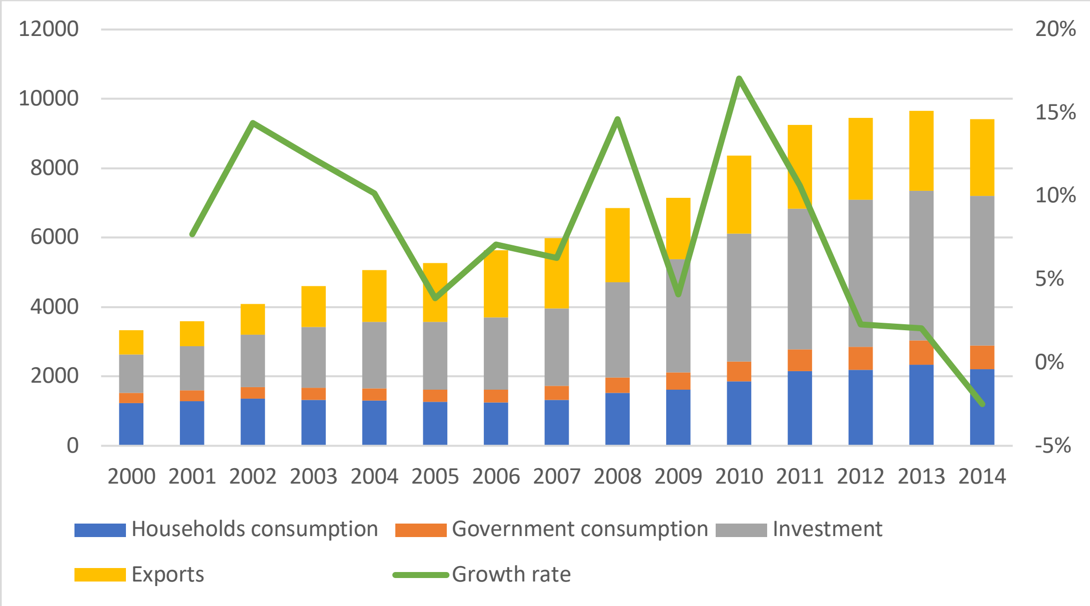

Figure 12 Carbon emissions induced by final demand (Mt) from 2000-2014, author's calculation

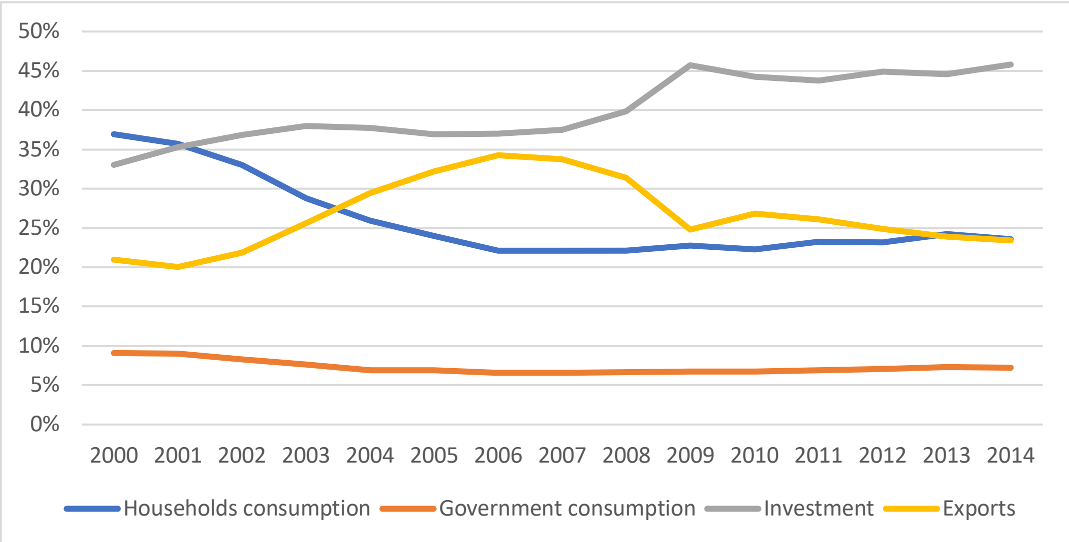

Figure 13 The percentage of CO2 Emissions for each component of final demand, author's calculation

From 2000 to 2007, China's GDP grew rapidly, and CO2 emissions increased correspondingly. During that period, consumption-driven carbon emissions increased from 1530 Mt in 2000 to 1725 Mt in 2007, with an average annual growth rate of 4,3%; the investment-driven carbon emissions increased from 1098 Mt to 2245 Mt, with an average annual growth rate of 14,9%; export-driven carbon emissions increased from 694 Mt to 2022 Mt, with an average annual growth rate of 27,3%. As a result, the proportion of CO2 contributions for final demand has changed. The proportion of consumption-driven carbon emissions has dropped from 46% in 2000 to 28% in 2007. The proportion of investment-driven carbon emissions rose from 33% to 38% and became the largest contributor; the proportion of export-driven carbon emissions rose from 21% to 34% and became the second contributor. All the analysis shows that the growth of carbon emissions during 2000-2007 is related to the changes in the demand structure, especially the growth of investment and exports.

Between 2007-2010, the total carbon emission growth rate decreased sharply in 2008 and then recovered a bit in 2009, which shows the big confluence of the 2008 financial crisis to China's greenhouse gas emissions. Among the three demands, export was affect mostly with a decrease of 4,52% and 15,82% in 2008 and 2009 respectively. The reflection was quicker than GDP as during the 2008 financial period people produced fewer products in 2008 which cause a reduction in carbon emissions.

From 2010-2014, the increased rate of carbon emissions slowed down and in 2014 it came to -0,36%, which means China has been starting reducing carbon emissions while still keeping economic growth. As for the demand structure, the carbon emission for investment took about 50% of the total emissions, and the emission for export was slightly less than it for consumption purposes.

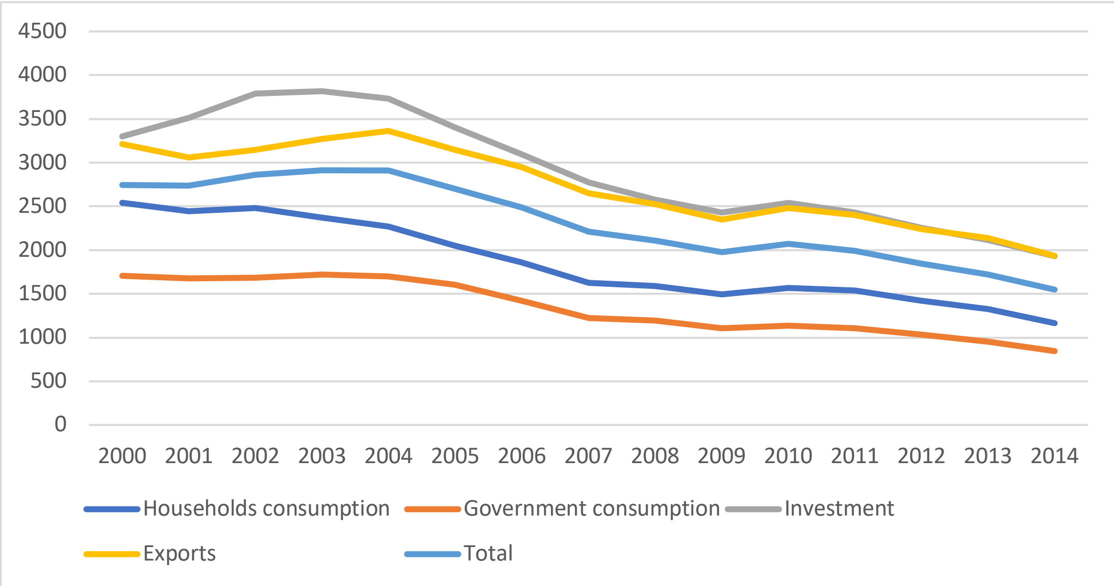

Figure 14 Carbon intensity (Mt/$trillion) from 2000-2014, author's calculation

The carbon intensity is the CO2 emissions per unit of output. It is an effective indicator measuring the effectiveness of carbon reduction policies in a country. Figure 13 shows the changes in carbon intensity between 2000-2014, and the results indicate that although the total amount of CO2 emissions in China has increased over the years, the carbon intensity has decreased, and the trend is similar for each final demand categories.

From a quantitative perspective, the carbon intensity of investment was the largest when it of government consumption was the smallest in each year between 2000-2014. While the carbon intensity of consumption (both government and household) had always been lower than the total carbon intensity of China, the carbon intensity of export and investment had been higher than the overall carbon intensity.

From the perspective of time, China's carbon intensity declined every year except for 2003 and 2010, and the decrease rate was quite sharp. In 2014, the total carbon intensity was 1547 Mt/ $trillion, which was 56,3% of it in 2000, with an average decline rate of 3,2%. The carbon intensity of household consumption, government consumption, investment and export in 2014 was 45,8%, 49,5%, 58,5%, 60,2% of the rate in 2000.

Among all types of final demand, the carbon intensity of household consumption has the largest decline, followed by government consumption, and the carbon intensity of export has the smallest decline.

The decrease in carbon intensity in consumption contributed to the overall carbon reduction. What causes differences in carbon efficiency? This question will be discussed later in the following chapter.

4.3 Drivers Affect the Carbon Emission

In this sector, we analyze the changes in the drivers of China's CO2 emission using the SDA model. According to the SDA decomposition formula, the influencing factors for carbon emission changes in China from 2000 to 2014 are decomposed into five main drivers, they are, national population, carbon emission intensity, production structure, consumption structure, and per capita GDP. We divide the period into three stages: 2000-2007 is the first stage, 2007-2010 is the second stage, and 2010-2014 is the third stage. The results are displayed in Figure 15.

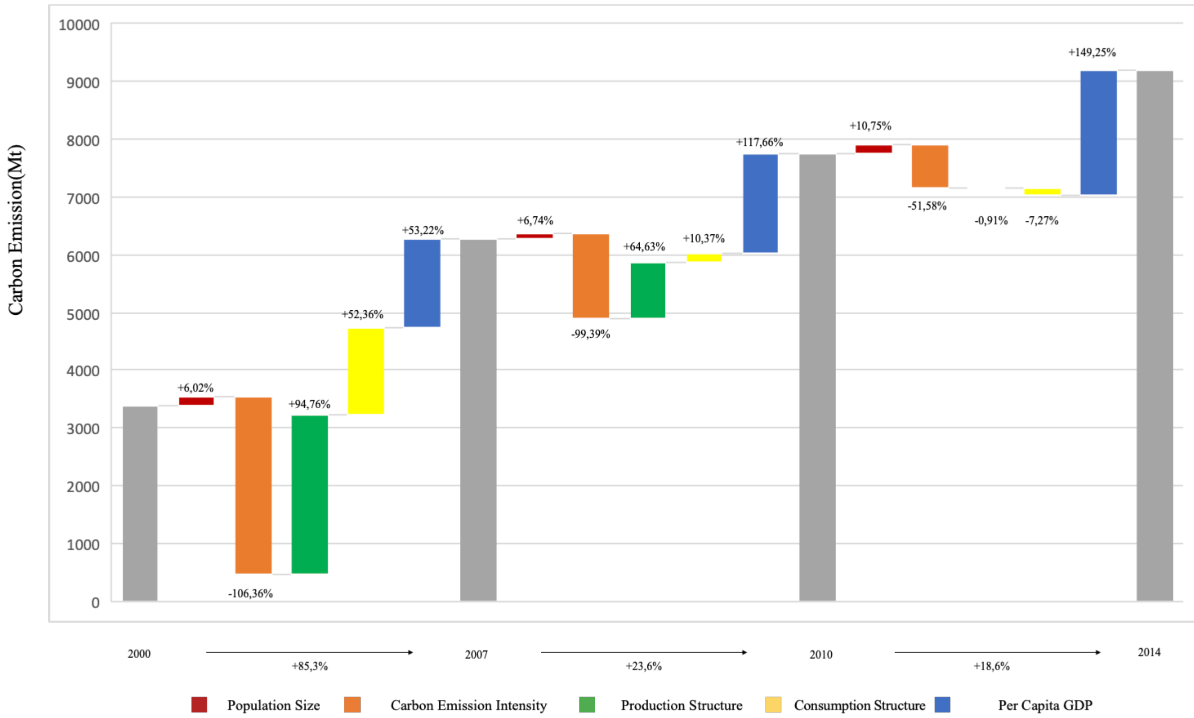

Figure 15 Contributions of different influencing factors to Carbon Emission changes in China between 2000-2014(Mt), author's calculation

In general, at all stages, the increase in carbon intensity has a positive effect on the reduction of carbon emissions, and the increase in population and per capita GDP promotes carbon dioxide emissions, and the promotion effect of per capita GDP is more obvious. The impact of the other two factors on carbon emissions changes over time.

4.3.1 Carbon Emissions Before the Financial Crisis (2000-2007)

From 2000 to 2007, carbon efficiency played the most essential role in offsetting carbon emission growth. The improvement of efficiency improvement contributed 16,16% of the total carbon reduction with other factors unchanged (Figure 15). At the same time, the other four factors (population, production structure, consumption structure, and economic growth) all improved the carbon emission level. The economic growth made the largest contribution and increased carbon emission by 22,96% per year with other factors remaining constant. The effects of production structure increased carbon emission by 6,21% while the consumption structure increased it by 1,84%. In addition, population growth led to the smallest growth (0,92% per year) in carbon emission.

China's carbon emission intensity declined fast during that period, which is because of the decline of energy intensity (total energy consumption per unit of output) and a change of fuel structure. We will discuss the impacts in next chapter.

4.3.2 Carbon Emissions During the Financial Crisis (2007-2010)

From 2007 to 2010, production structure and carbon emission intensity were two important factors that offsetting carbon emission growth with an average rate of 5,99% and 5,42% respectively. Consumption structure was another factor that offsetting carbon emission growth and it decreased the carbon emission by 2,85% per year. Per capita GDP was still the most essential factor driving the growth of energy consumptions and increased China's carbon emission by 18,64%. The driving effects of the population size was 1,67%(Figure 15).

The 2008 financial crisis greatly affected the Chinese economy. China's real GDP growth rate fell to 9.4% in 2010, which was far lower than the 14.2% in 2007. The slowdown in economic growth has affected carbon emissions. From 2000 to 2007, the average annual growth rate of China's carbon emissions was 15,8%, and from 2007 to 2010, this number had dropped to 4,95%, and the rate of the decline in carbon emissions growth exceeded that of GDP. To a certain extent, this is because the financial crisis severely affected exports (Figure 15). Investment, consumption, and exports are the three demand factors that promote China's economic development. Since joining the WTO in 2001, China has been active in the world market and has become a major export country. The economic growth has relied more and more on exports. Export-driven carbon emissions The increase is also increasing. From 2000 to 2007, China's export carbon emissions increased by 1.562 Mt, accounting for 41.96% of the total increase in carbon emissions during the same period. However, the advent of the financial crisis destroyed this upward situation. The average annual growth rate of China's exports fell from 53.72% in 2000-2007 to -3.2% in 2007-2010. In the same period, the carbon emissions caused by China's exports have been reduced by an average of 9,81% annually.

In contrast, between 2007 and 2010, China's carbon dioxide production through investment increased rapidly. In response to the economic crisis, the Chinese government has proposed a package plan to stimulate the domestic economy. It plans to invest four trillion yuan to increase the construction of infrastructure and people's livelihood projects. Therefore, 45.73% of China's carbon emissions growth in the period 2007-2010 was caused by government investment, which was much higher than that in 2000-2007 and 2010-2014.

4.3.3 Carbon Emissions in the New Normal (2010-2014)

In China's previous carbon emission growth model, the economic growth, changes in the production structure, and changes in the consumption structure are three significant factors that promote the growth of carbon emissions, and the improvement in efficiency has driven the decline of carbon emissions (Guan, 2009). From 2000 to 2007, changes in the production structure and consumption structure increased China's carbon emissions by 94.76% and 52.36%, respectively, while the increase in efficiency reduced China's carbon emissions by 106.36%. However, in the phase of new normal, structural changes in both the production and consumption side have become one of the factors that reduce China's carbon emissions.

There are two types of consumption: government consumption and household consumption. From 2000 to 2010, China's consumption rate (the proportion of final consumption in GDP) continued to decline, and it was as low as 41.1% in 2010. At the same time, the investment rate (the proportion of capital composition in GDP) reached the highest level. Therefore, the proportion of carbon emissions caused by China's consumption is also decreasing year by year. The contribution rate dropped from the highest point in 2000 to third place in 2010, lower than exports and investment. Under the new normal, the proportion of China's consumption-driven carbon dioxide emissions began to increase. Although the growth rate is not large, it is an indicator that shows the progress China has made in stimulating the domestic market and encouraging consumption. The National Information Center predicts that China's consumption demand will continue to grow in the future. Together with the investment, consumption will become an important force to promote national economic growth and increase carbon emissions.

Table 8 Comparison of results from retated studies

Source	Time period	population	efficiency	production structure	consumption structure	per capita GDP
This paper	2000-2007	6,02%	-106,36%	94,76%	52,36%	53,22%
	2007-2010	6,74%	-99,39%	64,63%	10,37%	117,66%
	2010-2014	10,75%	-51,82%	-0,91%	-7,27%	149,25%
Peng, 2012	2000-2005	2,35%	-13,03%	11,38%	60,07%	39,21%
	2005-2010	2,08%	-27,95%	25,76%	64,48%	35,68%
Liao &Xu, 2017	2002-2007	6,03%	-78,91%	-16,93%	59,08%	130,72%
	2007-2012	6,79%	-59,72%	-17,44%	15,00%	155,37%

Table 8 shows the comparison between the calculation results in this paper and other documents. We can see that the decomposition results are not the same for different studies. There are many reasons for the difference in results. Firstly, the research period chosen for different studies is different. As mentioned above, the stage is significant in studying the driving forces of CO2 emissions as during different time periods, the policies, developing goals, and economic environments are different. Secondly, the database selected varies for different studies; so the original data set is different. For example, the emission data from IEA considers fossil fuels only, while the data from CDIAC includes CO2 emissions both from fossil fuels and cement production. It will also cause errors. Thirdly, the studies did not use the same method and have the same restriction. The SDA method has n! different decomposition ways and researchers choose their methods freely. The estimation method is also different. For example, in Peng's study, he didn't consider the influence of inflation and used nominal GDP to do analysis, which would result in a higher influence of GDP growth on carbon emissions.

5. The Analysis of Five Main Drivers

5.1 The Population Size

The effect of population size in all stages is positive, which means that the change of population in China causes an increase in China's carbon emission. In 2000-2007, 2007-2010, and 2010-2014, the average annual contribution rate of population size to CO2 emissions was 0,86%, 2,24%, and 2,26 % respectively (Figure 15). The average contribution rate in all stages was less than 3%, which means that it is not the main driver for the increase in carbon emissions. In 2000-2007, 2007-2010, and 2010-2014, the average annual contribution rate of population size to CO2 emissions was 0,86%, 2,24%, and 2,26 % respectively (Figure 15).

China is a country with the largest population in the world, therefore considering the influence of population size is meaningful. Ever since the 1970s, it has adopted family planning as the basic state policy to control the population size (Chen, 1979). Though there remains controversy about this policy from the ethical perspective, it effectively helps with the slow down of the increase of population, control carbon emissions, and protect the environment. However, China is gradually stepping into an aging society, and the lack of working force gradually becomes a problem for the country. Under this circumstance, the plan of canceling the family controlling policy has been put on the agenda. In 2015, The National People's Congress of China passed amendments of the "Population and Family Planning Law", allowing each couple to have more than one kid if they fit some requirements. In 2020, the Civil Code of the People's Republic of China was published by the State Council, which officially announced the abolishment of a series of policies about family control (Wahlberg, 2020). Table 9 shows China's population size and prediction for the future (UN, 2019). According to the prediction, the peak of China's population will come in 2040, and afterward, the population will decrease. So the size of the population will not be the main driving factor that could increase carbon emissions in the future.

*Table 9 China's population size, the year with * means the prediction,(Source: China Statistic Yearbook 2011, World Population Prospects 2019)*

Year	2010	2020*	2040*	2050*
The population size at the end of the year (billion)	1,34	1,42	1,47	1,46
Average annual increase rate	0,56%	0,6%	0,16%	-0,068%

5.2 The Carbon Emission Intensity

Carbon emission intensity measures the amount of CO2 emitted per unit of output by each department and it is an important manifestation of the technological level. As displayed in Figure 13, carbon intensity is the most important driver that reduces CO2 emissions, and the study on the carbon emission intensity will help the reduce of carbon emissions in the future. Carbon emission intensity measures the amount of greenhouse gas emissions per unit of economic activities, usually measured at the national level of GDP, it is a composite indicator of two factors, energy intensity, and fuel mix. The equation is as following:

$$\frac{CO_2}{GDP} = \frac{Energy}{GDP} \times \frac{CO_2}{Energy} \qquad (25)$$

Where $\frac{CO_2}{GDP}$ repersents the carbon intensity, $\frac{Energy}{GDP}$ represents the energy intensity and $\frac{Energy}{GDP}$ represents the fuel mix.

The first part of emission intensity is the energy intensity, which is the number of energy used for every unit of GDP produced. This indicator not only shows a country's energy efficiency level but also reflects its overall economic structure. The next component of emission intensity is the fuel mixture, which is the carbon contents of specific energy used in a country. Coal has the largest carbon content, oil has the second largest, and then is natural gas. The energy structure is one main factor affecting the emission intensity.

For China's energy structure, coal consumption has always played a dominent role with the ratio over 66%. In 2000, the total consumption was 214,545 Mtce , and in 2014 it reached to 279.329 Mtce. The ratio of coal to total energy consumption dropped from 68, 5% to 65,6% in 2014, which was a very slight decrease. Oil consumption ranked the second in total consumption. It rose from 32,332 Mtce in 2000 to 74,09 Mtce in 2014, but the proportion decreased from 22% to 17,4%. The portportion for natural gas rose from 2,2% in 2000 to 5,7% in 2014 and the consumption ratio for other renewable energy such as wind and nuclear increased from 7,3% to 11,3%.

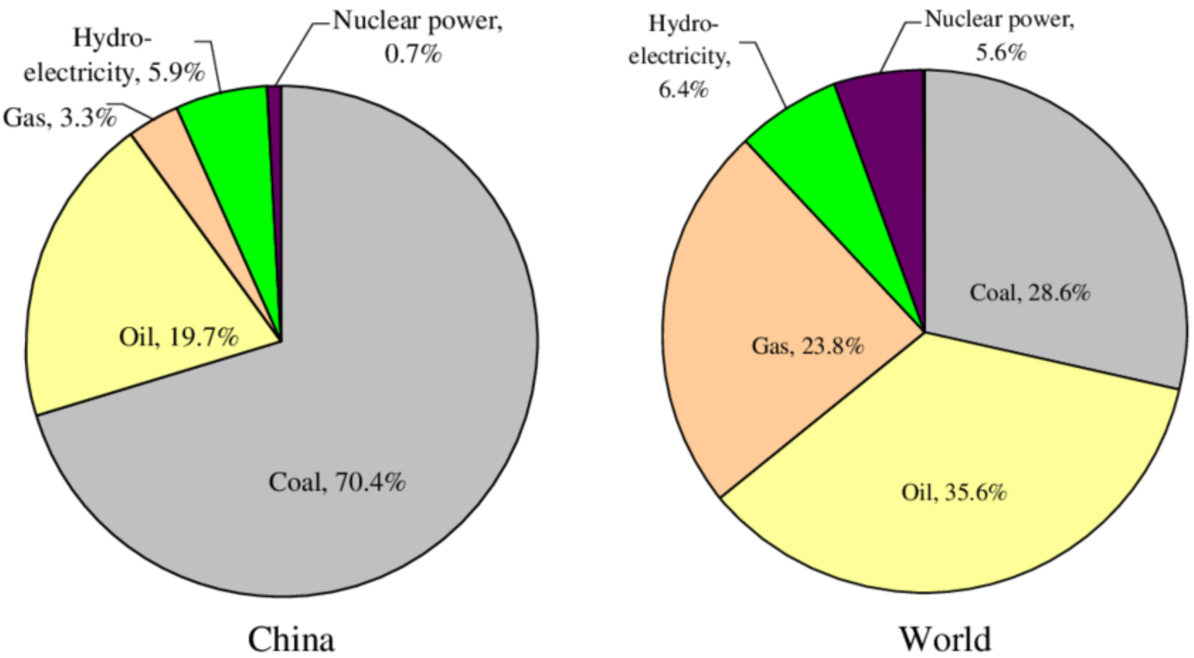

Figure 16 Comparison of energy consumption structure between China and the world in 2007, (Soucre: https://www.researchgate.net/publication/269041967_Factors_Influencing_the_Environmental_Satisfaction_of_Local_Residents_in_the_Coal_Mining_Area_China)

Compared with the energy consumption structure in the world, China relies too much on coal which has the highest carbon content, and it is more than two times over the world's average. Besides, the proportion of clean energy is small, which also hinders the improvement of carbon efficiency. The inappropriate energy construction in this country is one of the crucial blockers in reducing carbon emissions. In 2016, the reform of energy structure was discussed during the Chinese People's Political Consultative Conference(CPPCC). In the stage of new normal, actions are going to be done to improve the energy intensity.

Overall, changes in the energy structure have an impact on carbon dioxide emissions. One important feature of China's energy structure is that the proportion of its coal consumption is significantly higher than the rest of the countries in the world. The resource usage characteristics of "rich coal, poor oil, and low gas" determine that the main energy China consumed is coal. Among all energy sources, coal has the highest carbon dioxide emission content. This high carbon energy consumption structure makes it more difficult to reduce emissions, and there is still much room for adjustment of the energy structure.

Recent years, the problems of energy depletion and environmental pollution caused by the continuous growth of the energy consumption have become increasingly serious, and the contradiction between economic development and energy depletion and environmental pollution has become increasingly prominent. Therefore, it is an inevitable choice to adjust and optimize the energy consumption structure and reduce the excessive dependence of economic development on fossil energy. According to the characteristics of China's current energy consumption structure, the adjustment can be done from the following two aspects: On the one hand, it is difficult to change the coal-driven energy consumption structure in a short period of time, so it is necessary to adhere to the high-quality and efficient development of coal resources and reasonable and effective Utilization of coal, minimize the direct use of raw coal, increase the conversion utilization rate of coal, promote the clean use of coal, and expand the proportion of natural gas in energy consumption; on the other hand, gradually change the situation of the country's excessive consumption of energy resources. Compared with developed countries, the proportion of clean energy such as hydropower, wind power, solar energy, bioenergy, and nuclear energy in China is still relatively low. Non-fossil energy accounts for only 1% of primary energy consumption. Increasing the proportion of clean energy in total energy consumption and achieving diversification and low carbon consumption in energy consumption have become an inevitable trend. China will face a huge challenge in terms of technology and cost to promote clean energy on a large scale. Therefore, formulate China's clean energy development strategy, increase investment in clean energy projects, formulate industry standards and regulations, establish a system that is conducive to the large-scale development and use of clean energy, actively introduce advanced foreign clean energy technologies, and increase subsidies for clean energy related products should be the focus of the government's energy development policy.

5.3 The production structure

From Figure 17, we can see that the influence of the production structure to China's carbon emissions has undergone an important change from 2000 to 2014. The effects of production structure for reducing carbon emissions was negative from 2000-2010 but possitive from 2010-2014. The average annual contribution in 2000-2007, 2007-2010, 2010-2014 was 4,75%, -35,04% and 6,19% respectively. The carbon emission for industries vary, a deeper understanding of carbon emssion by product is useful.

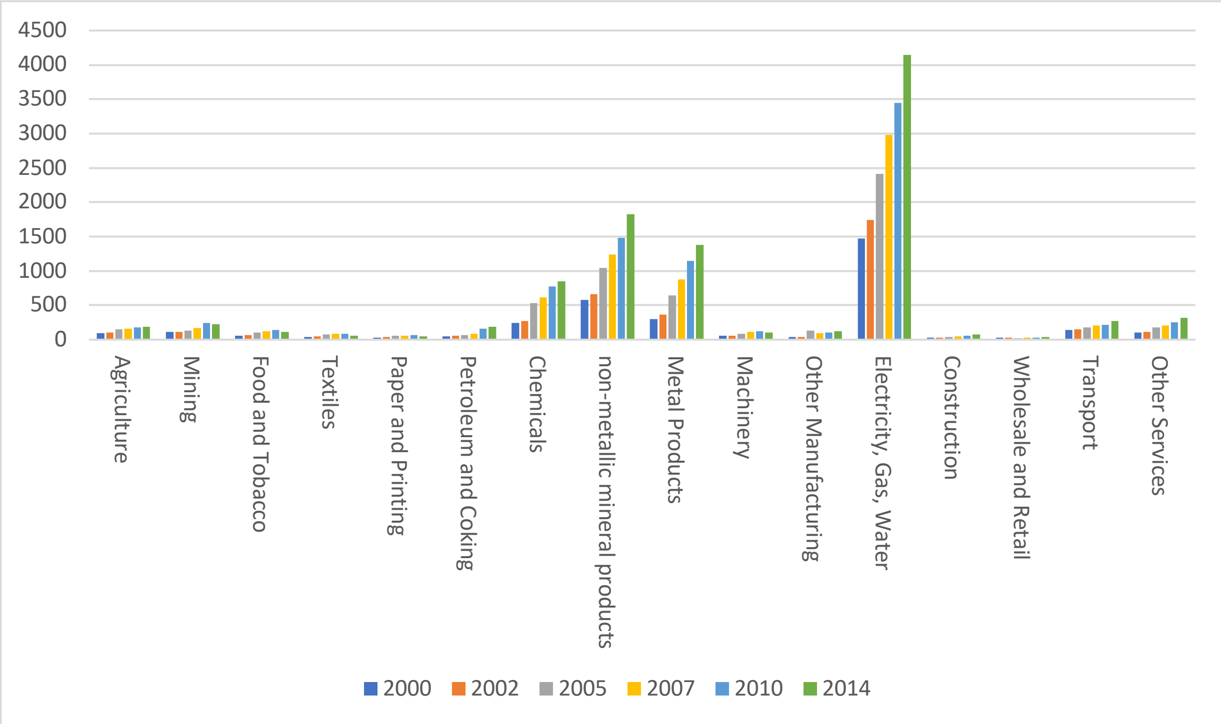

Figure 17 Carbon emission for different industries from 2000-2014 (Mt), author's calculation

According to the input-output equation, the carbon emission and carbon intensity of each industry in 2000, 2002, 2005, 2007, 2010, and 2014 are calculated, and the results are shown in Figure 17. From figure 17 we can see that the carbon emissions varies greatly in different industries. Among them, the carbon emission for the "electricity, gas, and water" emitted the most carbon emissions in both years. In 2014, it emitted 4144Mt CO2 with was 41,67% of the total emissions, it is because of the relatively high proportion of coal used in the industry's energy consumption structure. Besides, "metal products", "non-metallic mineral products" and "chemical" are also sectors which contributed high carbon dioxide emissions. It might because the production process of these industries depends on the direct input of a large amount of energy. On the contrary, the agriculture industry and tertiary industry have relatively lower carbon emission as those industries rely more on human capital than energy input.

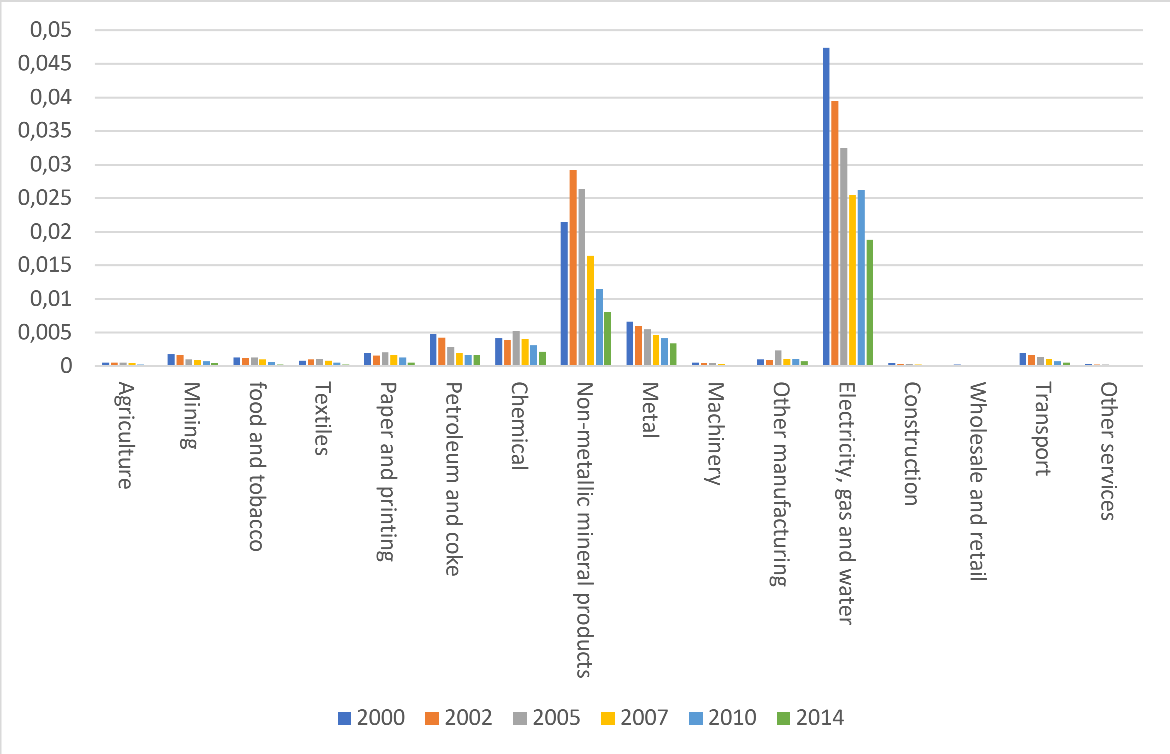

Figure 18 Carbon emission intensity by industry from 2000-2014(Mt/M$), author's calculation

As for the carbon intensity, from 2000-2014, the carbon intensity for almost all industries decreased, which was the main driver for the decrease of carbon emissions and showed the improvement of efficiency. As figure 18 displayed, the industries with high carbon intensity produce more carbon dioxide, and the industries with low carbon intensity produce less carbon dioxide. We need to pay more attention to the carbon-intensive industries such as electricity, gas and water, and non-metallic mineral products. To further understand the reasons for the changes in carbon emissions for different industries, the SDA model is used to do the decomposition analysis.

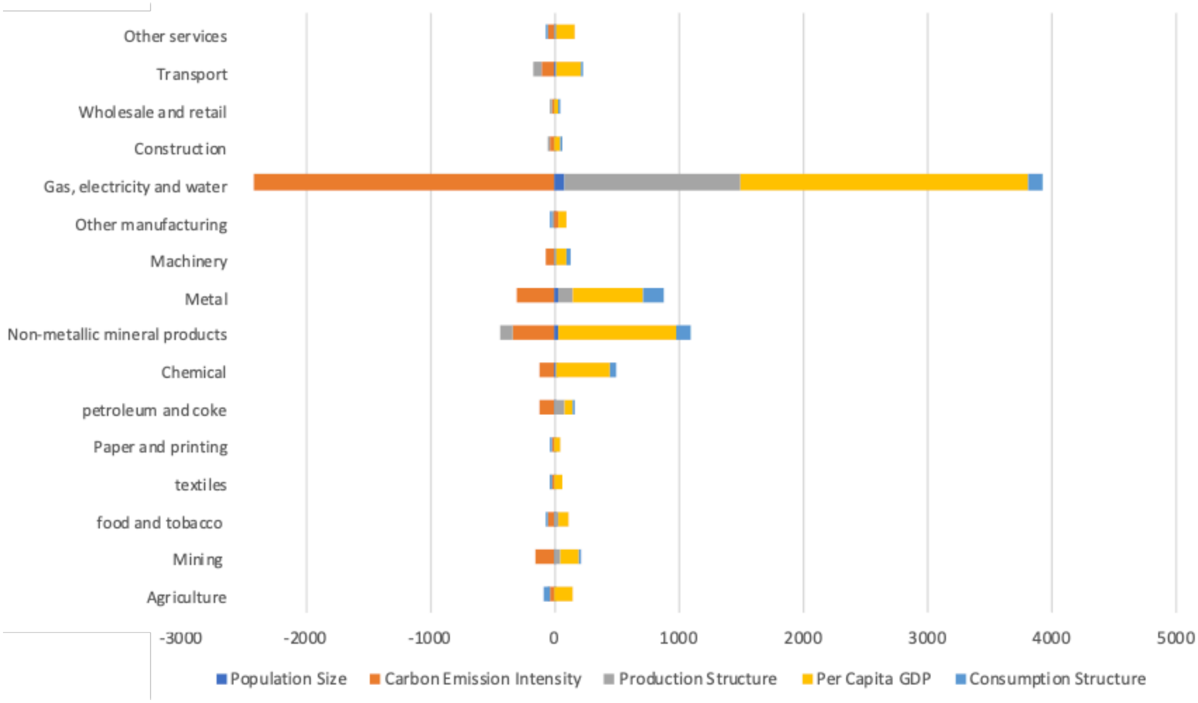

Figure 19 SDA results by industry from 2000-2007 (Mt), author's calculation

From Figure 19, we can see that for all industries except "wholesale and retail", the carbon emission increased in 2000-2007. Economic growth was the main driver for the increase of carbon emissions for all industries except wholesale and retail while the carbon efficiency help reduces carbon emissions for most of the industries except wholesale and retail and other manufacturing. The population size contributed to CO2 emissions for all industries was positive but the influence was small. And the effect of production structure and consumption structure increased carbon emissions for most energy-intensive industries like petroleum and coke, metal, construction, and ect.

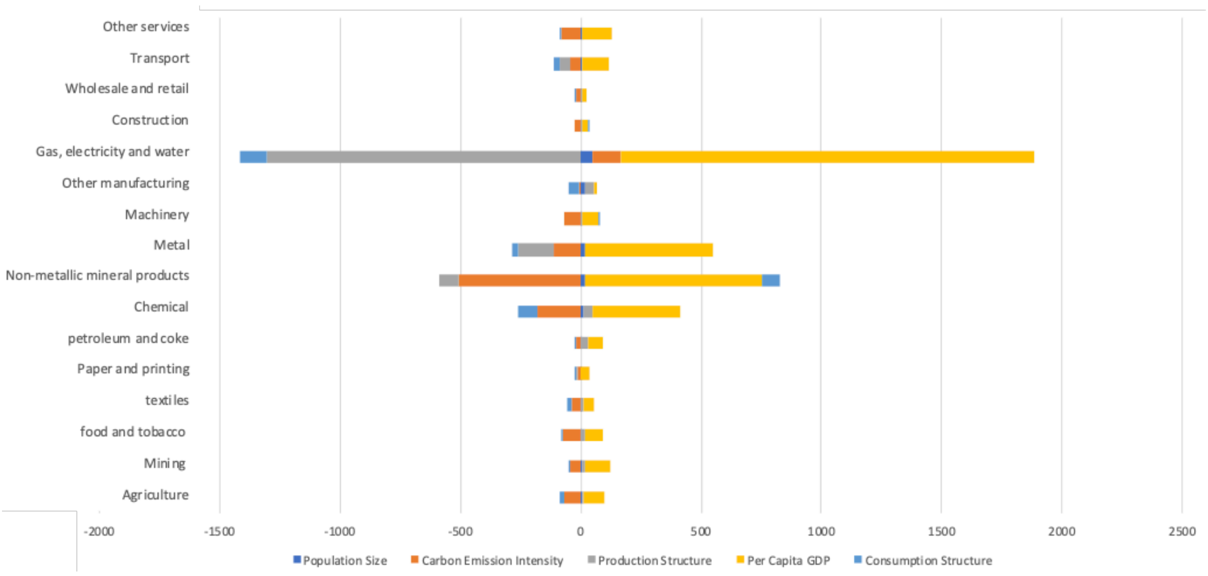

Figure 20 SDA results by industry from 2007-2010 (Mt), author's calculation

From Figure 20, we can see how things changed during the period of financial crisis. The population size was still a small but steady driver in the increase of carbon emissions for all industries while the economic growth being the big driver for the carbon emissions. The driver carbon intensity help reduce carbon emissions for all industries except “Electricity, gas, steam and air conditioning supply”, which means that at that stage the carbon efficiency in that industry didn’t improve during this period. As for production structure and consumption structure, the influence of financial crisis was not big for industries of domestic purpose, like the domestic service industry and construction. But for carbon-intensity industries which have exports, the changes of both production structure and consumption structure decreased the carbon emissions.

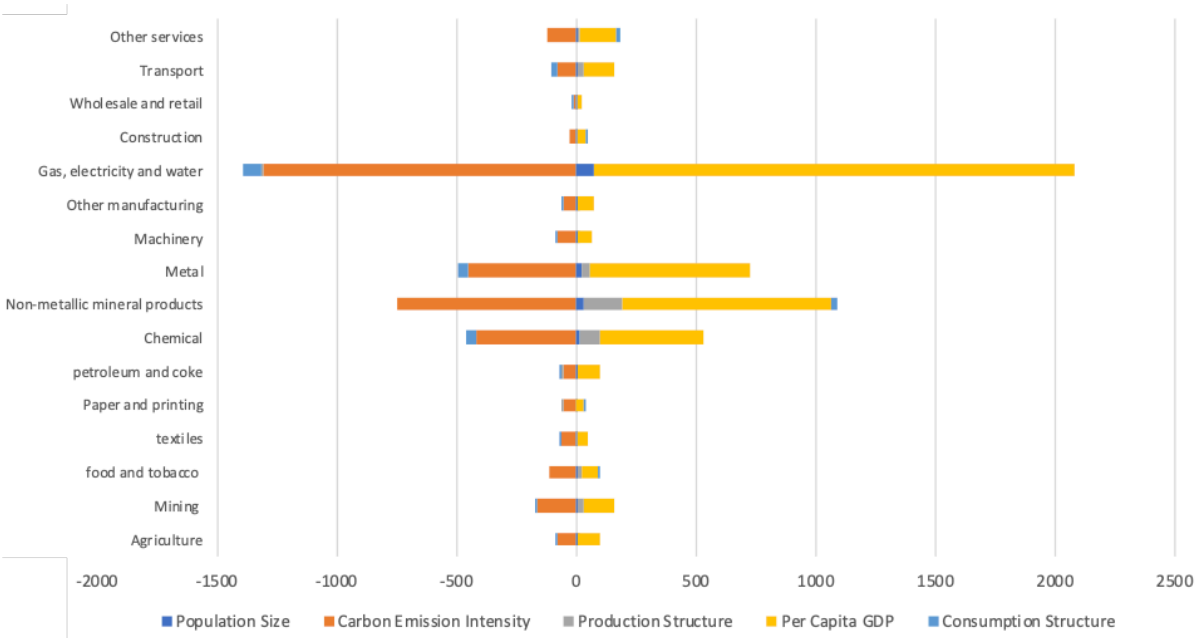

Figure 21 SDA results by industry from 2010-2014 (Mt), author’s calculation

From Figure 21, we can see that the industries had gradually been recovered from the financial crisis. Most of the average increase rate of carbon emissions per industry was lower than in 2000-2007, which shows that the work on reducing carbon emissions was effective. Economic growth was still the main driver for the increase of carbon emissions while the carbon intensity offset the effect. The population size was still a small but steady driver in the increase of carbon emissions for all industries. The influence of production structure and consumption structure differed as to the industry. For the first industry, the structure change of production and consumption decrease carbon emissions. For the secondary industry, the influence differed but it helps reduce carbon emissions for high carbon-intensity industries such as “Electricity, gas, steam and air conditioning supply”. Overall, the structure change during 2010-2014 helped reduce carbon emissions.

The result of SDA analysis shows that during the "New Normal" period, China actively promoted the optimization and upgrading of industrial structure, optimized development of the energy industry, encouraged production and consumption of renewable energy, and eliminated backward production capacity. Energy conservation and emission reduction efforts have achieved certain results. The carbon dioxide increase rate of various industries has achieved a certain degree reduce.

5.4 The Consumption Volume

GDP per capita is an important manifestation of the level of economic development. According to the analysis, economic growth was the most important driving force for the growth of China's carbon dioxide emissions from 2000 to 2014. It can be seen from Figure 15 that in 2000-2007, 2007-2010, and 2010-2014, the contribution of economic growth to carbon dioxide emissions was 52,24%, 117,65%, and 149,24%, respectively. The contribution rate is consistent with the GDP growth rate, and as the economic growth rate is declining, the influence of GDP per capita will not be as significant as before. Economic growth always leads to an increase in carbon emissions, and the overall growth rate depends on other driving factors, such as product structure and consumption structure.

5.5 The consumption structure

The consumption structure reflects the distribution of final products among consumption, investment, and exports. For the overall view, the consumption structure was an important contributor to the increase in carbon emissions. The increase rate was 52,35% between 2000-2007, 10,36% between 2007-2010, and -7,3% between 2010-2014. The influence of consumption structure has been discussed in previous chapters.

From the perspective of the consumption structure, due to the highest carbon dioxide intensity of investment and export, as they account for a large proportion of the final demand structure, the carbon intensity of the overall economy grow, and such final demand structure promotes the total carbon emissions for the whole economy.

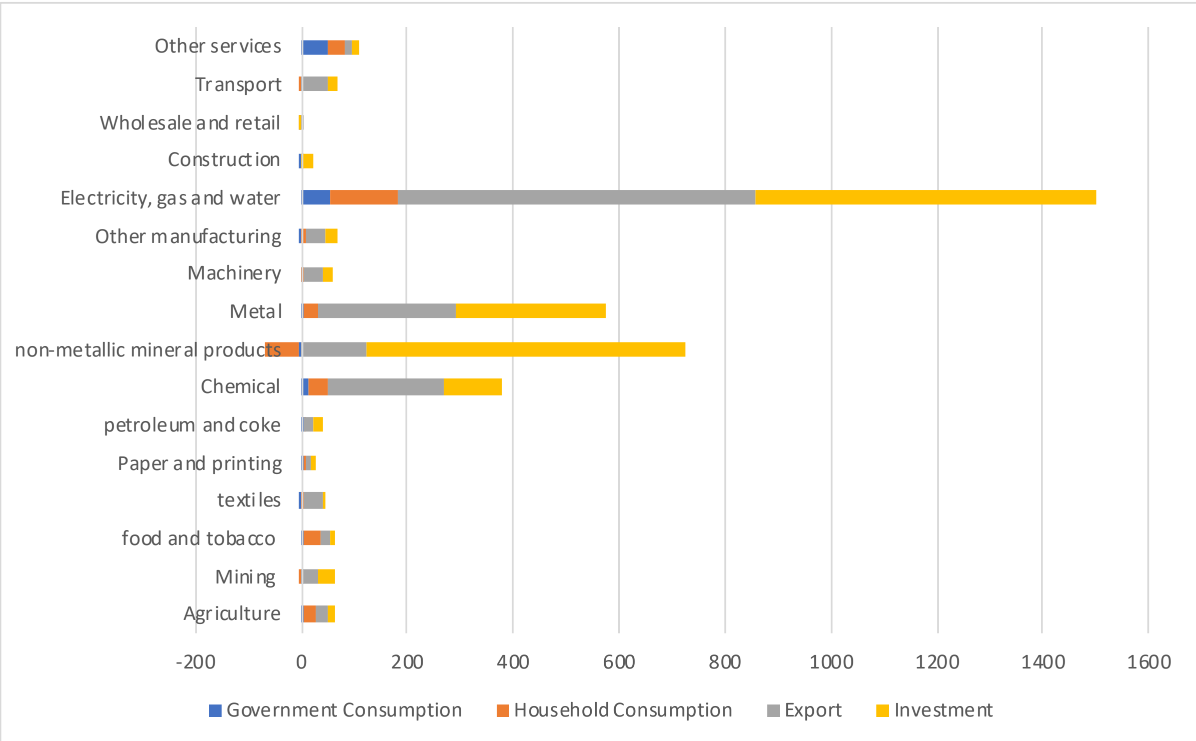

Figure 22 Components of Change in CO2 emissions From Consumption side from 2000-2007 (Mt), author's calculation

From 2000 to 2007, China's economy developed rapidly, and the carbon emissions of most industries increased as well. The increase was mainly driven by investment and exports. The surge in investment has led to an increase in carbon emissions in industries such as non-metallic mineral products and natural gas, electricity, and water. During this period, exports have also made a great contribution, especially in heavy industrial industries such as metal, chemical, non-metallic mineral products, and light industrial industries such as textiles. These industries have similar characteristics, most of them were energy and labor-intensive industries while the technology level was not high. It also fit China's role as the "world factory" at that time. At this stage, the effect of consumption on the growth of carbon emissions was not obvious, especially in the secondary industry.

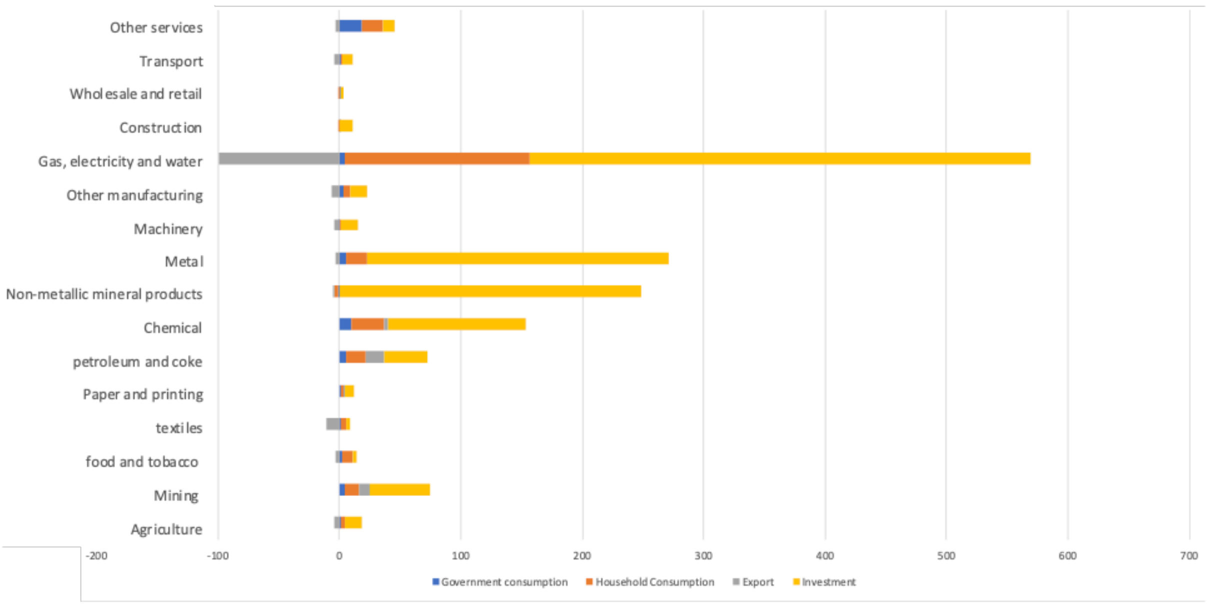

Figure 23 Components of Changes in CO2 emissions from Comsumption Side from 2007-2010 (Mt), author's calculation

From 2007 to 2010, because of the increase in investment demand, carbon dioxide emissions for most industries were still increasing. However, due to the impact of the 2008 financial crisis, the sharp decline in export demand became the main factor in reducing carbon emissions. Industries such as textiles that rely heavily on export had been affected severely. The reduced exports resulted in a decrease in carbon emissions for these industries. For other industries that rely heavily on investment, the "package plan" which was designed by the government to stimulate the economy during the financial crisis provided room for their development. As a result, the carbon emissions of industries such as metals, non-metallic mineral products, chemicals, and construction have increased rapidly, mainly due to increased investment in response to the financial crisis.

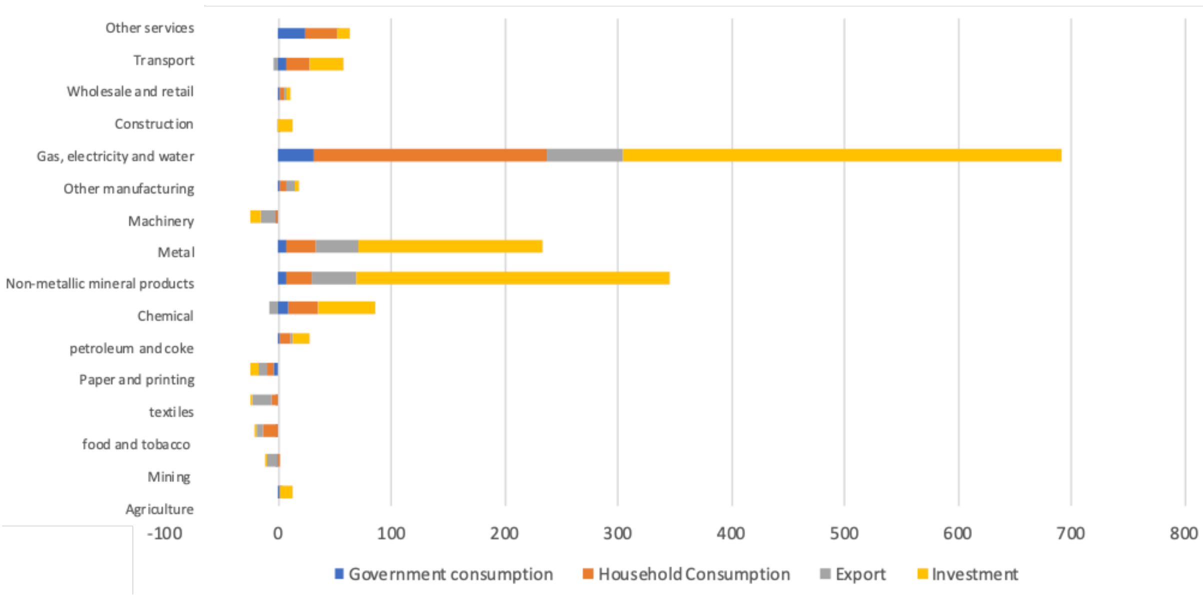

Figure 24 Components of Changes in CO2 emissions from Comsumption Side from 2010-2014 (Mt), author's calculation

From 2010 to 2014, the investment was still the main driver contributing to the increase of CO2 emissions for most industries such as agriculture, chemistry, non-metallic mineral products, metals, natural gas, electricity and water, etc. At the same time, the driving effect of consumption increased, especially in specific industries. For example, for the service industry, government and household consumption were the main factors contributing to the increase in carbon emissions. The impact of exports did not return to the same level as before the crisis. On the contrary, for certain industries, such as mining, textile, machinery, etc., the decline in export demand was still the main driving force for reducing carbon emissions. The most important thing in this stage was that for some industries especially secondary industries with high carbon intensity such as mining, food and tobacco, textiles, and Paper and printing, the total carbon emission started to decline. Though the amount was not large, it indicates that after entering the stage of new normal, The adjustment of the production structure was effective in reducing carbon emissions and can be applied in more industries.

6. Conclusion and Reflection

6.1 Conclusion and Innovation

6.1.1 Conclusion

The rapid growth of China's economy since the beginning of the 21st century has enhanced China's national strength and brought people a prosperous life. However, it also causes environmental and resource problems.

According to the calculation in this paper, China's total CO_2 emissions reached 9,946Mt in 2014, which is 294,5% of it in 2000. Later, this paper analyzed the changes in the final demand structure for carbon emissions using environmental extented input-output model. The results show that the contribution rate of consumption dropped from 46% in 2000 to 30,4% in 2014, which was a significant decline. The contribution rate of fixed capital formation rose from 33% in 2000 to 45.8% in 2014 and became the most important contributor since 2002. The contribution rate for exports increased from 20,9 % in 2000 to 23,4% in 2014. Besides, to analyze the impact of key factors driving China's carbon emissions growth, we introduced the SDA model. The five key driving factors are population, carbon emission intensity, production structure, final demand structure, and economic growth. The analysis results show that economic growth was the most important factor in driving the growth of CO_2 from 2000 to 2014. With other factors remaining constant, economic growth has increased CO_2 emissions by 93,5% compared with it in 2000. Consumption structure and industrial structure have also played a significant role in the growth of CO_2 emissions. From 2000 to 2014, the contribution rate of consumption structure and production structure was 63,3% and 28,5% respectively, showing that the significant influence of the economy on the environment.

On the contrary, the changes in carbon intensity due to technological progress and optimization of the energy structure contributed to the carbon reduction. Between 2000 and 2014, while keeping other factors unchanged, the reduction in carbon emission intensity reduced CO_2 emissions by 91%. The next step is to compare the driving factors in the following three stages: 2000-2007, 2007-2010, and 2010-2014. The results show that the role of production structure and consumption structure in reducing carbon emissions has undergone an important change from negative to positive. The carbon intensity has always help reducing carbon emissions and the influence has been further strengthened over time. The population effect has not been significant.

From 2000 to 2007, China's carbon emissions continued to increase, and the final demand structure also changed significantly. Ever since China entered the WTO in 2001, the dependence of economic development on exports had increased, and the export rate had also risen significantly. In 2007, the proportion of export-driven carbon emission reached a peak of 33,8%. During the same period, the proportion of consumption-driven carbon dioxide emissions had been declining from 46% to 37%. At that time, China's production structure dominated by the secondary industry was the main reason for the growth of carbon emissions, followed by economic growth.

The global subprime mortgage crisis that happened in 2008 affected China's carbon emission conditions greatly. Firstly, during the financial crisis period, China's average annual growth rate of carbon emissions dropped sharply. Between 2007 and 2010, China's carbon emissions grew at an average annual rate of 6%, which was far below the previous level. The main reason for this slowdown is the decline in China's economic growth rate due to the global financial crisis. Second, the export-driven carbon emissions have fallen during the financial crisis as the international market was hit hard by the financial crisis. The growth of export has always been a key factor in promoting China's economic development, . However, due to the decline in foreign demand, China's export growth rate has dropped rapidly. The decline in the export growth rate has led to a decline in carbon emissions from China’s exports from 2007 to 2014, especially in industries that are highly dependent on exports, such as the metal and textile product industries. From 2007 to 2010, carbon emissions caused by China's textile product exports dropped by 21%. From an end-user perspective, the carbon emissions caused by China’s exports in 2014 accounted for 22% of the total carbon emissions, which is much lower than the level before the crisis. Third, during the financial crisis, the number of carbon emissions generated by Chinese investment increased rapidly, from 41% in 2007 to 51% in 2009. The Chinese government has proposed a series of plans in response to the adverse effects causing by the global financial crisis. From 2007 to 2010, about 77% of China's CO_2 emission growth was induced by investment, which is much higher than before. From a sectoral point of view, between 2007 and 2010, the carbon emissions from the investment in the construction industry and metal products industry increased by 21% and 31%, respectively.

In the phase of New Normal, the factors that offset the growth of China's carbon emissions have begun to shift from efficiency improvements to structural upgrades. From 2000 to 2007, efficiency served as the only driving factor among all the five drivers that contributed to the decrease of carbon emissions. But things changed in 2010-2014. The consumption structure and production structure also help reduce carbon emissions. In previous development model, the production structure, as well as consumption structure, was initially the driver that irritate the increase of carbon emissions. However, in 2010-2014, the consumption structure reduced carbon emissions by 7.27%, and the production structure reduced carbon emissions by 0, 91%. This changing data shows China's successful structural reform and upgrade from both the perspective of production and consumption. From the perspective of production, the production structure has contributed to the reduction of China’s carbon dioxide emissions, because the proportion of carbon emissions products in total inputs (like mining, power sector inputs and transportation) has fallen. From a consumption-based perspective, consumption patterns have contributed to the decrease of China’s carbon emissions as the proportion of products that are not sensitive to end-uses (such as electrical equipment, power and chemical industries) has fallen.

In the New Normal stage, the CO_2 growth mode in China is shifting from the investment-dominent model to a synergy of investment, exports, and consumption. From 2000 to 2010, the proportion of CO_2 produced by consumption continued to decline, between 2010-2014, it increased by 2%. Though it is not a large growth, it reflects the results of China's new policies in the new normal stage that stimulates domestic consumption and expanding domestic demand. At this stage, China abandoned the traditional investment-driven economic growth model, and gradually turned to the coordinated development model of investment, export, and consumption, paying more attention to the quality of economic growth, caring more about ecological civilization and people’s livelihood. The proportion of CO_2 produced by consumption is expected to grow in the future, and China's CO_2 growth model is still transforming.

Generally speaking, China's carbon emissions have experienced rapid growth and was stable at a high level since 2014. In the future, through the adjustment of the industrial structure and final demand structure, it is expected to achieve a balance between economic growth and the reduction of carbon emissions.

6.1.2 Innovation

The issue of carbon dioxide emissions is associated with both economic and environmental issues, so many scholars have done researches in this area. Compared with the existing literature, the innovation and contribution of this paper are mainly in the following aspects.

1) The specific research period. The starting point of the research is 2000, while most of the existing literature uses the 1990s or even 1980s as the starting point. Compared with the 20th century, China has made significant progress in the reform of the political and economical structure and gets closer international correlation as well as more frequent foreign trade, etc. Therefore, the research based on the framework and data of the last century may have its limitations when serving as references for current status. The research period in this article is closer to the present, so it has more practical significance and can provide a more reliable reference basis for current policymaking.

2) Comprehensive consideration of environmental and economic issues. Environment and economic development complement each other. In the 14 years studied in this article, the economic development in China has experienced three different stages. This article combines the analysis of economic growth with the analysis of changes in carbon emissions to fully understand the relationship among the economic, policy, environmental, and other influencing factors of carbon emissions. Besides, this research focuses on the analysis of changes in carbon emissions under the new normal development model from 2010 to 2014, which is similar to the current situation which can work as a data basis for The economic environment recommendations.

3) Method innovation. This research combines the IPAT model with the SDA model and analyze the influencing factors of China's carbon emissions through different dimensions, which makes the analysis and final conclusion more comprehensive.

6.2 Recommendation

Carbon dioxide emission is one of the indicators reflecting the development of an economy, Generally speaking, when a country is in the early stage of industrialization, the carbon dioxide will increase with a high increase rate. With the continuous improvement of the industrialization level, economic development's reliance on energy consumption will decrease, and the intensity of carbon dioxide will decline gradually, and the CO_2 emission increase rate will decline as well(Sun, 1999).

According to the theory, as a developing country, China's energy demand will remain a large amount for a long period. It is not easy to reach the reduction target on the Paris Agreement and the Copenhagen Accord. After the study on China's CO_2 emissions from 2000 to 2014 and the changing structure in different economic stages. We can see that China's carbon emissions have plateaued at a certain level mainly due to changes in efficiency, and consumption patterns. Accordingly, we provide policy recommendations for further reducing carbon emissions.

6.2.1 The Improvement of Energy Efficiency

The previous results indicate that the decrease in energy intensity is the most important factor in reducing carbon dioxide. From 2000 to 2014, the Chinese government made progress in improving energy efficiency and reducing carbon intensity through effective control of energy use. From 2000 to 2014, China's energy intensity dropped by 65.67%. It sounds like a great improvement, but compared with other developed countries, there is still a huge gap. In 2018, China's energy intensity was 1.55 times that of the United States, 1.89 times that of Japan and 3.4 times that of the United Kingdom (Rithchie & Roser, 2019). The main reasons for high carbon intensity are irrational energy structure and backward technology. Therefore, improving energy efficiency and promoting advanced energy technologies are good ways to reduce carbon intensity.

Energy Structure

China's coal-reliance energy structure not only leads to excessive carbon dioxide emissions but deteriorates the air quality. There are some methods to optimize the energy structure. 1) Reduce the proportion of coal in total energy consumption, and shift the coal-based energy consumption strategy to a low-carbon and diversified energy consumption strategy. 2) Develop clean coal technologies such as large-scale coal gasification and circulating fluidized beds(CFB) to improve coal efficiency(Wall et al., 2009). 3) Encourage the development of new energy and renewable energy technologies, and develop clean energy, such as solar, wind, and hydropower, to replace traditional energy products such as fossil energy. At present, though the proportion of clean energy in total energy consumption is increasing year by year, there is still a huge space for improvement. The government needs to support the development of clean energy, such as giving financial subsidies to relative companies to promote research and development in this area.

Technology Innovation

Technology innovation is always a key topic for MOT students. Companies need technology innovation to improve energy utilization efficiency, energy conversion efficiency, and increase the comprehensive utilization of renewable energy, therefore reduce carbon emissions. Besides, the economic development stage of "new normal" also requires technological progress to improve the quality of economic growth. Technology innovation has the characteristics of high market risk and high R&D costs and high market risks. It requires support from the government through tax cuts and financial subsidies.

The transportation industry is one of the benchmarks that reduce carbon emissions through technological progress. In recent years, breakthroughs have been made in the development of green vehicles, including Fuel Cell Electric Vehicle(FCEV) and Electric Vehicle(EV). And these products have gradually been into the market. In 2009, the "Automotive Industry Adjustment and Revitalization Plan" was published(State Council, 2009), which stated the new strategy for green vehicle strategy, including focusing on the promotion of technologies in key parts(battery, electric engine, and electric control) and improvement of the public platform(technical standards and regulations, infrastructure, test & evaluation technology). With all the policy support, domestic companies such as BYD, NIO, Xpeng motors developed their technology and have launched a series of products. Afterward, a series of rules which encourage people to buy green vehicles were published. Taking Shenzhen as an example, if one purchases pure electric vehicles that meet the E6 standard, he can receive a subsidy of ¥110,000 (MOF, 2010). In 2011, the National People's Congress has updated the detailed rules of the tax law and reduced the tax on vehicles and ships that use new energy(NPC, 2011). With all the technological innovation and policy encouragement, green vehicles have gradually been accepted by consumers and have entered millions of households. In 2009, the sales of new energy vehicles in China was only about 5,000. By 2014, this number exceeded 300,000, and it has still increased rapidly. Technological innovation has enabled the upgrade of the industry and contributed to the reduction of carbon emissions.

6.2.2 The Adjustment and Optimization of Production Structure

The carbon intensity in different industries differs greatly, and the readjusting and optimizing of the industrial structure have a positive influence on reducing carbon emissions. As China is still in the intermediate period of industrialization, the secondary industry plays a dominant role in the industrial structure. The focus is to gradually reduce the ratio of secondary industry in the whole economy. Different policies should be made regarding different industries. For industries such as coal mining industry, chemical industry, petroleum and industry, transportation and storage industry, etc., a certain proportion should be maintained. Reduced, more energy-saving policies can be formulated in terms of technological progress. For non-metallic mineral products industry, handicrafts and other manufacturing industries, gas production and supply industry, water production and supply industry, and other sectors, the proportion can be reduced as much as possible on the basis of ensuring people's production and life. At the same time, the development of the tertiary industry should be encouraged and the proportion of the service industry in the industrial structure should be increased. The optimization and upgrading of the industrial structure are also beneficial to the adjustment of the energy consumption structure. Many sectors with higher carbon dioxide intensity are those with higher fossil energy consumption, while the tertiary industry sector consumes less coal. Optimizing the industrial structure is also beneficial. Will make the energy consumption structure more reasonable.

In the new normal phase, the government is also aware of this problem. In the 13th Five-Year Plan, the government emphasized the importance of adjusting and upgrading the industrial structure (Yu & Zhang, 2015). There are the following suggestions: 1) Promote the development of the tertiary industry and increase the proportion of high-tech and high value-added manufacturing. 2) For industries with high carbon intensity, introduce new technologies to reduce carbon intensity. 3) For new projects with high carbon intensity, the government should formulate energy-saving standards and energy-saving technical specifications to limit and eliminate industries with high energy consumption and high carbon emissions.

6.2.3 The Change of Consumption Structure

Optimizing and adjusting the demand structure is important in reducing carbon emissions. From the demand perspective, investment and exports contribute a large proportion to the growth of carbon emissions. This reflects the high investment rate and low consumption rate in China's demand structure in recent years. In 2014, the contribution rate of final consumption expenditure to carbon emission dropped to 29%, which was much lower than the contribution of investment. Due to the imbalance between investment and consumption, though the country is experiencing a renowned economic growth, people's living conditions cannot be improved simultaneously, resulting in limited domestic market scale and overproduction. On the other hand, China's low investment efficiency and high energy consumption per unit of output will inevitably lead to high carbon emissions.

Therefore, to ensure the stable growth of China’s economy while effectively reducing the carbon emission, we cannot unilaterally emphasize the growth of investment and exports. A balanced final demand structure with the coordinated growth of consumption, investment, and export is important in keeping a healthy economic environment. More detailed policies can be:

1) Encourage consumption and reduce the dependence on exports.

2) Decrease the scale of investment, and shift the investment focus from the secondary industry to the tertiary industry.

3) Change the export pattern and increase the proportion of exports of high value-added products.

6.3 Reflection

In this study, we chose the extended environmental input-output method and structural decomposition analysis method to evaluate the changing structure and influencing factors of CO2 emissions in China and made some conclusions which could be helpful in the reduction of carbon emissions in the future. However, there are still some improvements that can be made in the future.

In this paper, only carbon dioxide and its influencing factors are discussed. However, there are other greenhouse gases such as methane, nitrous oxide, CFC, HFC, etc. which also have adverse effects on the climate change, ecological environment, air quality (Montzka, Dlugokencky & Butler, 2011). The study on those greenhouse gases is less but it is also of great significance to do research on these gases and how to reduce them to better improve the environment.

The second thing is for the drivers of carbon emissions. We select five main drivers, population size, production structure, consumption structure, economic development, and energy efficiency for the study. However, there are more influencing factors such as the urbanization process, industrialization stage, and consumption habits which also affect the CO2 emissions. In further research, we can consider to make improvements and add these influencing factors to the model and do more comprehensive research.

Thirdly, in this study, we consider China as a whole. But because the country is very large, different provinces have different population, production structure, consumption preference and etc. The development strategy in Shanghai will not be the same as in Tibet. So we can do the same research for different provinces in the future.

Fourthly, one of the aims of the research is to provide a sample of how to keep a balance between economic growth and carbon reduction for other developing countries. Different countries have different environments, but this paper only studies what happens in China. Therefore, in future research, we can compare the economic growth and corresponding carbon emissions of other countries, analyze the environment of other countries, and then provide other developing countries with more feasible and meaningful experience.

During the period of writing the thesis, I applied a lot of skills I had learned in my MSc study in TPM. The basic concepts and assertions of the economic modeling came from the economic courses and mainly from the specialization of "economics and finance'"; The courses in this specialization include "economic foundations", "intermediate economics", and "economics and finance"; The elective "economic policy for sustainable energy" provided more idea on the project of energy economics. The decision-making process always exists in deciding the development strategy of a country and making new environmental policies. And innovation responsibility is important in developing new environmentally friendly technologies. As this study was empirical research focusing on scientific theories and numbers, it is more similar to an academic view than guidance which can be used directly in the real world. When applied it into the real industry, it could be more helpful and comprehensive, for example, if it forms as instructions to high energy-consumption companies on reducing CO2 emissions, besides the overall suggestions, there could be more specific ideas on how to change the proportions of energy and which technology can be applied to improve the efficiency.

Global climate change is a severe problem for human beings and needs the cooperation of the whole world. It is similar to a Prisoner's Dilemma, where countries only consider their own best choice instead of the maximin benefit for the earth, although the cost will only be paid in the future. However, the trend of deglobalization makes cooperation among countries more difficult. In 2017, the United States announced the withdrawal from the Paris Agreement, severely weakened global efforts to reduce greenhouse gas emissions. When doing this thesis research, I am glad that China takes its responsibility, but I am also considering how to make a more useful binding agreement that all countries would involve. It is a more complicated question than my research question, and I'll keep on thinking and caring about it in the future.

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Appendix

Table S1 CO2 emission factors for energy consumption (Source: General principles for calculation of the comprehensive energy consumption GB/T 2589-2008, People's Republic of China)

No.	Energy types	Emission factors ($Mt\ CO_2 / 10^4 t, 10^8 m^3$)
1	Raw coal	0,0162
2	Cleaned coal	0,0204
3	Other washed coal	0,0119
4	Briquettes	0,0138
5	Coke	0,0288
6	Coke oven gas	0,1153
7	Other gas	0,0596
8	Other coking products	0,0252
9	Crude oil	0,03
10	Gasoline	0,0293
11	Kerosene	0,0304
12	Diesel oil	0,0309
13	Fuel oil	0,0317
14	Liquefied petroleum gas	0,0313
15	Refinery gas	0,0334
16	Other petroleum products	0,0303
17	Natural gas	0,2161

Table S2 Price Index by Sector from 2000-2014 (Year 2000=100), (Source: China Statistic Yearbook 2000-2015)

Sector	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Agriculture	100	99,10	98,80	103,15	116,66	118,30	119,72	141,86	161,87	157,98	175,20	204,11	209,62	216,33	215,89
Mining	100	106,50	118,81	127,13	147,34	174,14	184,21	194,16	255,12	251,29	278,58	307,00	297,79	264,14	235,08
Food and Tobacco	100	100,50	100,14	101,24	107,82	108,79	109,20	117,39	128,66	126,61	131,42	139,70	142,77	144,48	143,18
Textiles	100	98,70	93,50	95,56	100,05	100,33	102,51	103,23	104,57	102,27	112,11	124,56	120,32	120,08	119,36
Paper and printing	100	99,70	97,57	96,30	97,55	98,89	99,57	100,56	106,40	100,44	103,90	107,02	105,42	102,99	102,17
Petroleum and Coking	100	99,10	94,35	109,07	124,56	152,49	183,44	189,68	224,77	186,78	232,97	290,05	288,89	278,78	269,86
Chemicals	100	97,10	94,81	96,99	104,46	111,54	112,31	115,90	124,48	114,65	122,42	134,42	129,04	124,78	122,29
nonmetallic mineral products	100	98,70	96,53	98,75	104,77	109,94	113,24	116,75	124,80	118,06	124,56	135,89	140,51	141,35	140,36
Metal Products	100	98,60	96,20	102,75	120,11	128,31	132,48	143,61	160,70	137,88	150,82	169,97	151,27	146,73	133,82
Machichinery	100	96,80	93,09	90,30	89,76	89,13	89,49	89,75	90,65	88,30	88,52	90,91	90,73	89,74	89,29
Other Manufacturing	100	98,70	96,53	98,75	104,77	109,94	113,24	116,75	124,80	118,06	124,56	132,03	129,78	127,32	124,90
Electricity, gas, water	100	102,30	103,07	103,99	106,49	110,91	113,97	116,48	118,58	121,30	123,67	135,29	138,00	140,90	145,83
Construction	100	100,40	100,60	102,81	108,57	110,31	111,96	116,33	126,68	123,64	128,09	136,55	138,05	138,46	139,16
Wholesale and retail	100	99,20	97,91	100,06	105,67	106,51	107,58	111,67	118,25	116,84	120,46	126,36	128,89	130,69	132,00
Transport	100	101,00	100,09	99,59	99,99	101,49	104,74	105,57	107,90	106,39	108,19	111,01	112,34	112,56	112,79
Other Services	100	100,70	99,89	101,09	105,04	106,93	108,53	113,74	120,45	119,61	123,55	130,23	133,61	137,09	139,83

Table S3 Carbon Emission caused by final demand from 2000-2014(Mt)

Year	Government Consumption	Household Consumption	Export	Investment	Total Final Demand
2000	340	1213	679	1145	3376
2001	347	1251	701	1283	3581
2002	336	1283	836	1423	3878
2003	348	1293	1097	1765	4503
2004	365	1315	1442	2072	5194
2005	431	1367	1795	2289	5882
2006	437	1356	2098	2622	6513
2007	467	1428	2241	2964	7100
2008	455	1459	2140	3197	7250
2009	467	1564	1802	3970	7802
2010	522	1690	2135	4153	8500
2011	581	1923	2277	4516	9297
2012	583	1917	2236	4774	9511
2013	636	2092	2270	4988	9986
2014	609	2013	2230	5093	9946

Table S4 GDP created by final demand from 2000-2014 (trillion)

Year	Government Consumption	Households Consumption	Export	Investment	Total Final Demand
2000	0,17269	0,48869	0,21488	0,32219	1,19845
2001	0,19504	0,53115	0,23219	0,36645	1,32483
2002	0,20643	0,55873	0,27965	0,40900	1,45381
2003	0,21573	0,58904	0,35736	0,47883	1,64097
2004	0,23613	0,65292	0,47021	0,57236	1,93162
2005	0,27678	0,72347	0,59769	0,65922	2,25716
2006	0,32024	0,81552	0,76041	0,81701	2,71319
2007	0,41071	1,05918	0,96270	1,06248	3,49506
2008	0,52637	1,33472	1,16574	1,49449	4,52131
2009	0,58053	1,48805	1,03488	1,88678	4,99024
2010	0,70285	1,74227	1,32280	2,16323	5,93115
2011	0,88531	2,21446	1,59670	2,66646	7,36293
2012	1,00730	2,49339	1,71926	3,09885	8,31879
2013	1,18281	2,91511	1,83478	3,44766	9,38036
2014	1,28634	3,16996	1,98136	3,84632	10,28398

Table S5 The Carbon Intensity (CO2 emission/ GDP) from 2000-2014(Mt/$Trillion)

Year	Government Consumption	Households Consumption	Export	Investment	Total Final Demand
2000	1969	2482	3160	3554	2817
2001	1779	2355	3019	3501	2703
2002	1628	2296	2989	3479	2667
2003	1613	2195	3070	3686	2744
2004	1546	2014	3067	3620	2689
2005	1557	1890	3003	3472	2606
2006	1365	1663	2759	3209	2400
2007	1137	1348	2328	2790	2031
2008	864	1093	1836	2139	1604
2009	804	1051	1741	2104	1563
2010	743	970	1614	1920	1433
2011	656	868	1426	1694	1263
2012	579	769	1301	1541	1143
2013	538	718	1237	1447	1065
2014	473	635	1125	1324	967

Table S6 Total energy consumption ratio from 2000-2014

Year	Raw Coal	Cleaned Coal	Other Washed Coal	Briquettes	Coke	Coke Oven Gas	Other Gas	Other Coking Products	Crude Oil	Gasoline	Kerosene	Diesel Oil	Fuel Oil	LPG	Refinery Gas	Other Petroleum Products	Natural Gas	Process
2000	58,83%	0,82%	2,08%	0,34%	9,85%	0,93%	2,31%	0,14%	0,66%	3,40%	0,88%	6,85%	3,56%	1,51%	0,76%	0,00%	1,30%	5,78%
2001	57,48%	0,78%	2,06%	0,33%	10,02%	0,89%	3,95%	0,14%	0,62%	3,22%	0,82%	6,79%	3,56%	1,31%	0,69%	0,05%	1,36%	5,91%
2002	59,02%	0,59%	1,96%	0,33%	10,08%	0,87%	2,68%	0,14%	0,61%	3,19%	0,79%	6,92%	3,23%	1,41%	0,67%	0,06%	1,37%	6,07%
2003	59,57%	0,84%	1,82%	0,35%	10,65%	0,82%	2,31%	0,15%	0,61%	2,99%	0,70%	6,47%	3,20%	1,35%	0,58%	0,06%	1,39%	6,13%
2004	59,23%	1,09%	2,02%	0,31%	10,55%	0,86%	2,42%	0,16%	0,48%	2,93%	0,68%	6,73%	3,14%	1,31%	0,58%	0,08%	1,42%	6,00%
2005	58,34%	0,99%	1,82%	0,28%	12,72%	1,08%	2,97%	0,14%	0,49%	2,63%	0,60%	6,28%	2,40%	1,15%	0,58%	0,12%	1,67%	5,75%
2006	58,05%	0,98%	1,88%	0,32%	12,71%	1,05%	3,27%	0,15%	0,49%	2,63%	0,58%	6,21%	2,27%	1,12%	0,53%	0,07%	1,72%	5,98%
2007	57,32%	1,00%	2,03%	0,36%	13,03%	0,93%	4,21%	0,18%	0,38%	2,46%	0,57%	5,89%	1,94%	1,08%	0,51%	0,09%	1,97%	6,04%
2008	57,27%	1,19%	2,07%	0,37%	12,95%	1,15%	3,87%	0,20%	0,29%	2,65%	0,58%	6,18%	1,46%	0,95%	0,53%	0,07%	2,20%	6,02%
2009	56,77%	1,18%	2,13%	0,37%	13,53%	1,04%	4,24%	0,21%	0,27%	2,46%	0,60%	5,71%	1,17%	0,88%	0,56%	0,08%	2,27%	6,51%
2010	55,76%	1,11%	2,10%	0,86%	13,56%	1,06%	4,27%	0,20%	0,25%	2,57%	0,67%	5,74%	1,07%	0,85%	0,56%	0,13%	2,31%	6,92%

2011	56,26%	1,13%	1,84%	0,83%	13,37%	1,07%	4,59%	0,18%	0,16%	2,54%	0,63%	5,53%	0,88%	0,80%	0,55%	0,12%	2,57%	6,98%
2012	55,91%	1,08%	1,89%	0,84%	13,68%	1,01%	4,36%	0,14%	0,18%	2,63%	0,65%	5,76%	0,79%	0,76%	0,54%	0,10%	2,69%	6,99%
2013	55,29%	1,03%	1,67%	0,85%	13,27%	1,01%	4,95%	0,17%	0,17%	2,87%	0,69%	5,56%	0,75%	0,82%	0,54%	0,08%	2,90%	7,36%
2014	52,91%	1,24%	1,91%	0,90%	13,71%	1,03%	5,35%	0,16%	0,18%	3,03%	0,75%	5,62%	0,76%	0,94%	0,58%	0,10%	3,16%	7,67%

Table S7 Carbon Emission changes for different final demand (Mt)

		Population Size	Carbon Emission Intensity	Production Structure	Per Capita GDP	Consumption Structure	Total changes
Government consumption	2000-2002	3	-20	-41	61	-9	-5
	2002-2005	7	-81	75	163	-67	96
	2005-2007	5	-132	4	194	-35	35
	2007-2010	7	-70	-131	266	-17	55
	2010-2014	11	-233	-25	305	29	87
Household Consumption	2000-2002	13	-52	-48	227	-73	65
	2002-2005	25	-377	226	564	-352	85
	2005-2007	15	-446	42	606	-156	61
	2007-2010	23	-211	-324	833	-60	262
	2010-2014	36	-789	8	993	76	322
Export	2000-2002	8	-16	-31	136	57	154
	2002-2005	24	-386	242	541	539	960
	2005-2007	22	-637	83	878	101	447
	2007-2010	33	-275	-383	1164	-645	-106
	2010-2014	42	-904	120	1151	-315	94
Investment	2000-2002	13	53	-119	230	96	273
	2002-2005	34	-598	523	773	134	867
	2005-2007	28	-922	280	1139	152	676
	2007-2010	54	-610	-634	1912	468	1189
	2010-2014	89	-1888	254	2450	33	938
Total	2000-2002	37	-35	-239	654	70	486
	2002-2005	90	-1443	1065	2040	254	2008
	2005-2007	69	-2137	409	2816	62	1219
	2007-2010	117	-1166	-1472	4175	-254	1400
	2010-2014	177	-3814	357	4899	-178	1441

Code for the study

#Input-Output Analysis

```
setwd('~/Desktop/TRy')
library(xlsx)
library(readxl)

# load data(Y is the output data, R & A are the original input-
output data)
Y <- read_excel("Y.xlsx", 1, skip = 15)
R <- read_excel("R.xlsx", 1, skip = 15, col_names = FALSE)
A <- read_excel("A.xlsx", 1, skip = 15, col_names = FALSE)

# calculate the Leontief matrix
A1<-as.matrix(A)
I<-diag(16)
L=solve(I-A)
options(scipen = 200)

# Calculate Total Carbon Emission
TC_1<-L%*%as.matrix(Y$`Total Final Demand`)*R
w<-TC_1/sum(YF$TC)

# Calculate Carbon Emission by Household Consumption
FCH_1<-data.frame(L%*%as.matrix(Y$`Final consumption expenditure by
households`)*R)
W1<-FCH_1/sum(YF$GCF)

# Calculate Carbon Emission by Government Consumption
FCG_1<-L%*%as.matrix(Y$`Final consumption expenditure by
government`)*R
W2<-FCG_1/sum(YF$EX)

# Calculate Carbon Emission by Investment
FI_1<-L%*%as.matrix(Y$FC)*R
w3<-FI_1/sum(YF$GCF)

# Calculate Carbon Emission by Export
FE_1<-L%*%as.matrix(Y$Exports)*R
w4<-FX_1/sum(YF$EX)
WiL<-rbind(w1,w2,w3)
TT<-rbind(TC_1,FCH_1,FCG_1,FI_1, FE_1)

# Write exel file
write.xlsx(TT,"TT.xlsx", col.names=TRUE, row.names=TRUE,
append=FALSE, showNA=TRUE)
```

#SDA Analysis

```
setwd('~/Desktop/TRy')
library(xlsx)
library(readxl)

A0 <- read_excel("Ad.xlsx", sheet = "2000",col_names = FALSE)
At <- read_excel("Ad.xlsx", sheet = "2007",col_names = FALSE)
F0 <- read_excel("B.xlsx", sheet = "2000", col_names = FALSE)
Ft <- read_excel("B.xlsx", sheet = "2007", col_names = FALSE)
Y0 <- read_excel("Yd.xlsx", sheet = "2000",col_names = TRUE)
Yt <- read_excel("Yd.xlsx", sheet = "2007",col_names = TRUE)
p<- read_excel("SDA.xlsx", sheet = "P",col_names = TRUE)
Ys<- read_excel("SDA.xlsx", sheet = "Ys",col_names = TRUE)

p0<-p$'2000'
pt<-p$'2007'
Ys0<- Ys$'2000'
Yst<- Ys$'2007'
I<-diag(16)
L0=solve(I-A0)
Lt=solve(I-At)

Eg1=1/2*(pt-p0)*(Yst*Lt%*%as.matrix(Yt$`Government
Consumption`)*Ft+Ys0*L0%*%as.matrix(Y0$`Government Consumption`)*F0)
Eg2=1/2*(Ft-F0)*(p0*Yst*Lt%*%as.matrix(Yt$`Government
Consumption`)+pt*Ys0*L0%*%as.matrix(Y0$`Government Consumption`))
Eg3=1/2*((Lt-L0)%*%as.matrix(p0*Yst*Yt$`Government
Consumption`)*F0+(Lt-L0)%*%as.matrix(pt*Ys0*Y0$`Government
Consumption`)*Ft)
Eg4=1/2*(Yst-Ys0)*(p0*L0%*%as.matrix(Yt$`Government
Consumption`)*F0+pt*Lt%*%as.matrix(Y0$`Government Consumption`)*Ft)
Eg5=1/2*(p0*Ys0*L0%*%as.matrix(Yt$`Government Consumption`-
Y0$`Government Consumption`)*F0+pt*Yst*Lt%*%as.matrix(Yt$`Government
Consumption`-Y0$`Government Consumption`)*Ft)
Eg=rbind(Eg1,Eg2,Eg3,Eg4,Eg5)

Eh1=1/2*(pt-p0)*(Yst*Lt%*%as.matrix(Yt$`Household
Consumption`)*Ft+Ys0*L0%*%as.matrix(Y0$`Household Consumption`)*F0)
Eh2=1/2*(Ft-F0)*(p0*Yst*Lt%*%as.matrix(Yt$`Household
Consumption`)+pt*Ys0*L0%*%as.matrix(Y0$`Household Consumption`))
Eh3=1/2*((Lt-L0)%*%as.matrix(p0*Yst*Yt$`Household
Consumption`)*F0+(Lt-L0)%*%as.matrix(pt*Ys0*Y0$`Household
Consumption`)*Ft)
Eh4=1/2*(Yst-Ys0)*(p0*L0%*%as.matrix(Yt$`Household
Consumption`)*F0+pt*Lt%*%as.matrix(Y0$`Household Consumption`)*Ft)
Eh5=1/2*(p0*Ys0*L0%*%as.matrix(Yt$`Household Consumption`-
Y0$`Household Consumption`)*F0+pt*Yst*Lt%*%as.matrix(Yt$`Household
Consumption`-Y0$`Household Consumption`)*Ft)
Eh=rbind(Eh1,Eh2,Eh3,Eh4,Eh5)

Ee1=1/2*(pt-
p0)*(Yst*Lt%*%as.matrix(Yt$`Export`)*Ft+Ys0*L0%*%as.matrix(Y0$`Expor
t`)*F0)
```

```
Ee2=1/2*(Ft-
F0)*(p0*Yst*Lt%*%as.matrix(Yt$`Export`)+pt*Ys0*L0%*%as.matrix(Y0$`Ex
port`))
Ee3=1/2*((Lt-L0)%*%as.matrix(p0*Yst*Yt$`Export`)*F0+(Lt-
L0)%*%as.matrix(pt*Ys0*Y0$`Export`)*Ft)
Ee4=1/2*(Yst-
Ys0)*(p0*L0%*%as.matrix(Yt$`Export`)*F0+pt*Lt%*%as.matrix(Y0$`Export
`)*Ft)
Ee5=1/2*(p0*Ys0*L0%*%as.matrix(Yt$`Export`-
Y0$`Export`)*F0+pt*Yst*Lt%*%as.matrix(Yt$`Export`-Y0$`Export`)*Ft)
Ee=rbind(Ee1,Ee2,Ee3,Ee4,Ee5)

Ei1=1/2*(pt-
p0)*(Yst*Lt%*%as.matrix(Yt$`Investment`)*Ft+Ys0*L0%*%as.matrix(Y0$`I
nvestment`)*F0)
Ei2=1/2*(Ft-
F0)*(p0*Yst*Lt%*%as.matrix(Yt$`Investment`)+pt*Ys0*L0%*%as.matrix(Y0
$`Investment`))
Ei3=1/2*((Lt-L0)%*%as.matrix(p0*Yst*Yt$`Investment`)*F0+(Lt-
L0)%*%as.matrix(pt*Ys0*Y0$`Investment`)*Ft)
Ei4=1/2*(Yst-
Ys0)*(p0*L0%*%as.matrix(Yt$`Investment`)*F0+pt*Lt%*%as.matrix(Y0$`In
vestment`)*Ft)
Ei5=1/2*(p0*Ys0*L0%*%as.matrix(Yt$`Investment`-
Y0$`Investment`)*F0+pt*Yst*Lt%*%as.matrix(Yt$`Investment`-
Y0$`Investment`)*Ft)
Ei=rbind(Ei1,Ei2,Ei3,Ei4,Ei5)

Et1=1/2*(pt-p0)*(Yst*Lt%*%as.matrix(Yt$`Total
Demand`)*Ft+Ys0*L0%*%as.matrix(Y0$`Total Demand`)*F0)
Et2=1/2*(Ft-F0)*(p0*Yst*Lt%*%as.matrix(Yt$`Total
Demand`)+pt*Ys0*L0%*%as.matrix(Y0$`Total Demand`))
Et3=1/2*((Lt-L0)%*%as.matrix(p0*Yst*Yt$`Total Demand`)*F0+(Lt-
L0)%*%as.matrix(pt*Ys0*Y0$`Total Demand`)*Ft)
Et4=1/2*(Yst-Ys0)*(p0*L0%*%as.matrix(Yt$`Total
Demand`)*F0+pt*Lt%*%as.matrix(Y0$`Total Demand`)*Ft)
Et5=1/2*(p0*Ys0*L0%*%as.matrix(Yt$`Total Demand`-Y0$`Total
Demand`)*F0+pt*Yst*Lt%*%as.matrix(Yt$`Total Demand`-Y0$`Total
Demand`)*Ft)
Et=rbind(Et1,Et2,Et3,Et4,Et5)

write.xlsx(Eg,"EE.xlsx", sheetName="Government Consumption",
col.names=TRUE, row.names=TRUE, append=FALSE, showNA=TRUE)

write.xlsx(Eh,"EE.xlsx", sheetName="Household Consumption",
col.names=TRUE, row.names=TRUE, append=TRUE, showNA=TRUE)
write.xlsx(Ee,"EE.xlsx", sheetName="Export", col.names=TRUE,
row.names=TRUE, append=TRUE, showNA=TRUE)
write.xlsx(Ei,"EE.xlsx", sheetName="Investment", col.names=TRUE,
row.names=TRUE, append=TRUE, showNA=TRUE)
write.xlsx(Et,"EE.xlsx", sheetName="Final Demand", col.names=TRUE,
row.names=TRUE, append=TRUE, showNA=TRUE)

#execute the same code for period 2007-2010 and 2010-2014
```