Scenario Analysis of a Local-scale Low Carbon Society in China

An Application of Shanghai

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Preface

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I am also grateful for all the lecturers who give us wonderful lectures. Thanks to Arne Strøm who is a very considerate and serious lecturer, and mathematics 3 is my favorite course. I would like to thank Geir B. Asheim, Karine Nyborg, Kjell Arne Brekke, Michael Hoel, Olav Bjerkholt and Tapas Kundu, whose lectures leave me a deep impression.

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Summary

Climate change is a global issue and threatens the basic element of life for people around the world. Lots of countries have set up targets and take measures to mitigate carbon dioxide emissions. China has also set up its own target to reduce carbon dioxide emission per unit of GDP by 40%-45% in 2020 compared to the level of 2005. This thesis develops a framework to estimate the emission level of carbon dioxide at local (or city) level in China by scenario analysis. This framework is applied to Shanghai in order to find a feasible way to reduce carbon dioxide emission.

This thesis sets up four scenarios (i.e. Business As Usual Scenario, Transformation Scenario, Moderate Intervention Scenario and Strong Intervention Scenario) to assess the activity level and energy efficiency in industrial, commercial, residential and transportation sector. According to the assumptions on economic growth, population growth and the changing trend of activity level, final energy consumptions in industrial, buildings and transportation sectors are calculated. Industrial sector has the largest contribution to total reduction amount, buildings sector is the second contributor and transportation sector has the smallest contribution.

According to the assumptions on energy structure, carbon dioxide emission is estimated. Under BAU scenario, total carbon dioxide emission will reach 46172 (10 000 tons CO_2), and carbon dioxide per capita will reach 19.93 $tCO_2 / person$ in 2020. However, carbon dioxide per unit of GDP will decrease by 39% compared to the level of 2005, which doesn't achieve the target. Under transformation and moderate intervention scenarios, total carbon dioxide emission and carbon dioxide per capita will be on the rise from 2010 to 2020, while carbon dioxide per unit of GDP will decline by 47% and 54% respectively. Under strong intervention scenario, total carbon dioxide emission will reach 26041 (10 000 tons CO_2) in 2016 and then it will decline gradually. Carbon dioxide per capita is around 12.7 $tCO_2 / person$ from 2008 and 2011, and afterwards it will be on the decline. Carbon dioxide per unit of GDP will decline by 58%, which achieve the target.

This thesis also identifies countermeasures for Shanghai to mitigate carbon dioxide

emission and classifies them as energy demand control, energy efficiency improvement and energy structure measures. The main countermeasures are to enhance energy efficiency, optimize energy structure, adjust industrial structure, set efficient and fast transportation system, and develop energy-saving technologies.

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1、Introduction

1.1 Background

Human economic activities lead to climate change which causes the increase of average temperatures, widespread melting of snow and ice, the rising of average sea level, the rising of the frequency of extreme weather and so on. On the other hand, global climate change also threatens the basic elements of life for people around the world—access to water, food production, health, the use of land and the environment (Stern, 2006). Carbon dioxide is the most important anthropogenic GHG. In 2008, carbon dioxide emission is 29381 Mt in the world, while the emission level in 1973 is 15643 Mt (IEA, 2010).

Climate change is a global issue related to extensive externality, thus its real challenges are the worldwide cooperation and persevering efforts. From the United Nations Framework Convention on Climate Change (UNFCCC) to the Kyoto Protocol, from the Bali Roadmap to Copenhagen Climate Change Conference and post-Kyoto Protocol era, more and more countries have taken actions to mitigate carbon dioxide emission. Although each country has to consider its own benefit and trade off between economic development and carbon dioxide emission reduction, low carbon society is their common objective.

China, as the most populous developing country, plays a special and important role in the world. With rapid economic growth, industrialization and urbanization, China's carbon dioxide emission is increasing dramatically. According to BP Statistical Review of World Energy (2010), China's carbon dioxide emission is 2477.3 million tons in 1990 while the emission level in 2009 is 7518.5 million tons which accounts for 24.2% of total emission in the world. The average annual growth rate of carbon dioxide emission is 3.07% from 1990 to 2000, while it is 9.37% from 2001 to 2009. In 2008, China has become the largest emitter of carbon dioxide in the world, exceeding the United States[1].

As a large energy consumption and carbon dioxide emission country, China has the responsibility to reduce the emission level. The major goals are set up as follows:

- In 2005, 'the 11th five-year plan' proposed that the main target for the environment is to reduce energy consumption per unit of GDP by 20% and total discharge of major

[1] According to the data from BP Statistical Review of World Energy (2010), China's carbon dioxide emission in 2008 is 6907.9 million tons, while the United States' is 6369.1 million tons.

pollutants by 10%.

- In 2007, the State Council issued notice to implement China's National Climate Change Program.
- On September 2007, Chinese President Jintao Hu expounded China's stance on tackling climate change at the 15th Economic Leaders' Meeting of the Asia-Pacific Economic Cooperation (APEC) forum. He said, 'we should optimize the energy structure, promote industrial upgrading, develop low-carbon economy, build a resources-conserving and environment-friendly society.'
- On November 2009, the State Council announced that China is going to reduce carbon dioxide emissions per unit of GDP in 2020 by 40%-45% compared with the level of 2005.

China has made a determination to develop low carbon economy and has taken measures to reduce carbon dioxide emission step by step, but in terms of China's current stage of development it also faces a lot of difficulties. First, China is a country abundant with coal, scarce of natural gas and lack of oil, and the difficulty in developing clean energy is not negligible. The exploitation of uranium mine can't keep up with the economic growth, so the development of nuclear power is limited to international market. Since the core technology develops slowly and the supporting facilities fall behind, there are lots of uncertainties to develop wind and solar energy. Exploitation of water resource contradicts the scarcity of territorial resource and the protection of ecological sensitive area. Thus, China doesn't have the advantage of developing renewable energy and energy structure can't be changed easily in the near future. Energy consumption will be still dependent on coal. Second, in the next twenty years, China's industrialization, urbanization and modernization is still in the boom period. In view of large scale and high speed of economic growth, current and future intensive urban construction will accelerate the need of high energy-consumption products such as cement, steels and nonferrous metal. The third is the difficulty in the transformation of economic growth pattern which is the basic way to solve the problem. However, since it involves in every field of social and economic activities, it is quite difficult to transform the extensive economic growth pattern.

To make a conclusion, it is hard to change the situation that the consumption of fossil fuel and the emission level of carbon dioxide will continue to increase in the short run. Therefore, China is facing unprecedented challenge—how to keep economic growth and mitigate carbon dioxide emission simultaneously. It is urgent for China to find a feasible way to reduce carbon dioxide emissions per unit of GDP in 2020 by 40%-45% compared with the level of 2005.

To achieve the above target, cities will play an important role. In 1978 China's urbanization rate is 17.92% while it increases to 45.68% in 2008. The next two decades are the boom period of urbanization. There will be 300-450 million people moving into the cities (UN, 2007; MGI, 2008). The increase of energy consumption in China's cities not only results from rapid industrialization but also from urban transportation and buildings. The impact of cities on carbon emission is becoming more and more important. Cities (including towns) use over two-thirds of the world's energy and account for more than 70% of global carbon dioxide emissions (IEA, 2008). In China, urban areas contribute 84% of total commercial energy consumption and 75% of total primary energy demand in 2006 and are responsible for 85% of energy related carbon dioxide emissions (Dhakal, 2009; IEA, 2008). Therefore, city will be the main battlefield to advance the mitigation of carbon dioxide emission. Low carbon city will represent for the future development direction in China.

1.2 Literature Review

Scenario analysis is an important tool used to address the complexity and uncertainty of future challenges. The first scenarios were probably designed to help plan military operations, often called 'war games', and then scenarios are increasingly used by enterprises around the world for many commercial purposes (Nakicenovic and Swart, 2000). Nowadays, scenario analysis is widely used. Many global studies have applied scenario analysis as a tool to assess future carbon dioxide emissions. One of these studies was Energy in a Finite World, conducted by the International Institute of Applied Systems Analysis (IIASA) and another influential series of scenarios was developed by the World Energy Council (Nakicenovic and Swart, 2000).

IPCC special report defined scenarios as "alternative images of how the future might unfold and are an appropriate tool with which to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties". Scenarios can be characterized as ‘exploratory’ and ‘normative’. Exploratory scenarios are those that begin in the present and explore trends into the future, while normative scenarios start with a prescribed vision of the future and then work backwards in time to visualize how that future could emerge (CGER, 2007). Generally, scenario analysis includes a definition of problem boundaries, a characterization of current conditions and processes driving change, and identification of critical uncertainties and assumptions on how they are resolved and images of the future (Swart et al., 2004).

For building up scenarios, the general principle can be summarized as follows: First, define the topic and focus of the scenario analysis, and determine the length of time horizon and the number of alternative scenarios. Second, identify the driving forces on future carbon dioxide emissions such as demographic development, socio-economic development and technological change, and reviewing the current status and the changing trend of these driving forces. Third, the revolutions of each variable are assessed by different models, based on assumptions about driving forces under different scenarios. Finally, different future images of carbon dioxide emission can be shown through qualitative and quantitative assessment.

In addition to the global studies on carbon dioxide emission, some countries have set up the target to curb carbon dioxide emissions by 2050, with the UK targeting reduction by 60%, Japan by 70%, France by 75% and Germany by 80% from the 1990 level (Shimada et al., 2007; LCS, 2008). Some studies focus on the quantitative estimation of the long-term reductions at national or sector levels (Treffers et al., 2005; Kadian et al., 2007; Tol, 2007; Ross, 2009; Dagoumas and Barker, 2010; Henriques et al., 2010; Wang and Watson, 2010; Ou et al., 2010). At the same time, there are also some studies to make quantitative assessment of emissions on the local scale (California Environmental Protection Agency, 2006; Greater London Authority, 2007). Compared to national level, city plays an important role to implement concrete measures to mitigate carbon dioxide emission and a lot of cities have set up the targets (see table 1-1)

Table 1- 1 Targets for Mitigating Carbon Dioxide Emission in Different Cities

Cities	Plan for Carbon Dioxide Emission Reduction	Targets
Chicago	Chicago Climate Action Plan	25% below 1990 levels by 2020, 80% by 2050
Hong Kong	Hong Kong Climate Change Strategy and Action Agenda	50%-60% below 2005 baseline levels by 2020
London	The Mayor's Climate Change Action Plan	60% below 1990 baseline levels by 2025
Los Angeles	Green Los Angeles	35% below 1990 baseline level by 2030
Madrid	Plan for the Sustainable Use of energy and Climate Change Prevention	20% below 2004 baseline levels by 2020, 50% by 2050
New York	Climate Change component of PLANYC	30% below 2007 baseline levels by 2030
Paris	Paris Climate Plan	75% below 2004 baseline by 2050
Seoul	Seoul Low Carbon Green Growth Master Plan	40% below 1990 baseline levels by 2030
Sydney	City of Sydney Environmental Management Plan	70% green gas emission reduction by 2030 based on 2006 levels
Tokyo	Climate Change Strategy	25% greenhouse gas emissions by 2020
Toronto	Climate Change, Clean air and Sustainable Energy Action Plan	6% below 1990 baseline levels by 2012, 30% by 2020, 80% by 2050
Amsterdam	Amsterdam Climate Change Action Plan	40% below 1990 baseline levels by 2025
Copenhagen	Copenhagen Climate Plan	20% below 2005 baseline levels by 2010
Stockholm	The City of Stockholm's Climate Initiatives	60%-80% below 1990 baseline levels by 2050

Source: C40 Cities Climate Leadership Group, http://www.c40cities.org/ccap/

However, few scenario studies are found to estimate carbon dioxide emission at local or city level. Compared to national level, local or city level studies have to consider the diversity of regional characteristics and the availability of data. Thus, under different frameworks for quantitative design, each study uses different methods. Shimada et al. (2007) employed a local macro economy tool to estimate the economic activity of Shiga prefecture in Japan; then they used activity calculation tool to estimate the activity level of various sectors including industrial, residential, commercial, passenger transportation and freight transportation sectors; finally, they calculated total energy consumption and the emission level of carbon dioxide. Gomi et al. (2010) improved the model of Shimada et al. and proposed a method to develop local (city-level) low-carbon society scenarios based on the export-base approach of standard regional economics. This method was applied to Kyoto city. The export-base approach considered that demand from outside of the region (exports) would induce production in the other industries through demanding intermediate input and consumption of laborers. And the output by industry was calculated by the standard input-output analysis. Li et al. (2010) set up two scenarios (BAU scenario and Basic-policy scenario) to assess carbon dioxide emission in Shanghai until 2020. This study estimated energy demand and carbon dioxide emission in primary, secondary, tertiary industry and residential sector based on the assumptions on economic development, population growth, economic structure and energy structure. Phdungsilp (2010) used the Long-rang Energy Alternatives Planning (LEAP) System model to simulate how energy demand and usage might develop in Bangkok from 2000 to 2025. Energy demand module is based on five sectors: commercial, industry, government, residential and transport. Using extrapolation and growth rate methods, the future energy demand and carbon dioxide emission are estimated.

This thesis aims at setting a suitable framework of quantitative design to estimate carbon dioxide emission on local scale in China and applies this method to assess carbon dioxide emission in Shanghai.

1.3 Methodology and Framework

This thesis will use the following methodology in the study of Shimada et al. (2007) and Gomi et al. (2010):

(1) Determine objectives such as a target region, base year, target year, low-carbon target(s) and number of scenarios.

(2) Describe the scenarios which can include assumptions on population, economic growth, industrial structure, lifestyle of the residents (such as energy consumption of households), means of transportation (by private car, metro, bus or taxi), energy structure and so on.

(3) Set detailed values of the indices to estimate the activity level of industrial, commercial, residential and transport sectors, based on the description of (2).

(4) Calculate the amount of energy demand required to satisfy the activity level of each sector and the emission level of carbon dioxide.

$$C = \sum_i D_i \cdot e_i \cdot ce$$

where C denotes total carbon emission level; D_i denotes the level of service demand in sector i； e_i denotes energy consumption per unit of service demand in sector i, which can represent energy efficiency; ce denotes the emission level of carbon dioxide per unit of energy consumption, which can represent energy structure.

(5) Set countermeasures in the target year.

(6) Identify countermeasures set.

The parameters set in (3) and (5) are input, and socio-economic indicators, energy demand and carbon dioxide emissions are estimated. If the emission level doesn’t achieve the low-carbon target, return to (5), setting countermeasures, and iterate this process until the low-carbon target is achieved.

According to the above methodology, the framework is set up in the following figure.

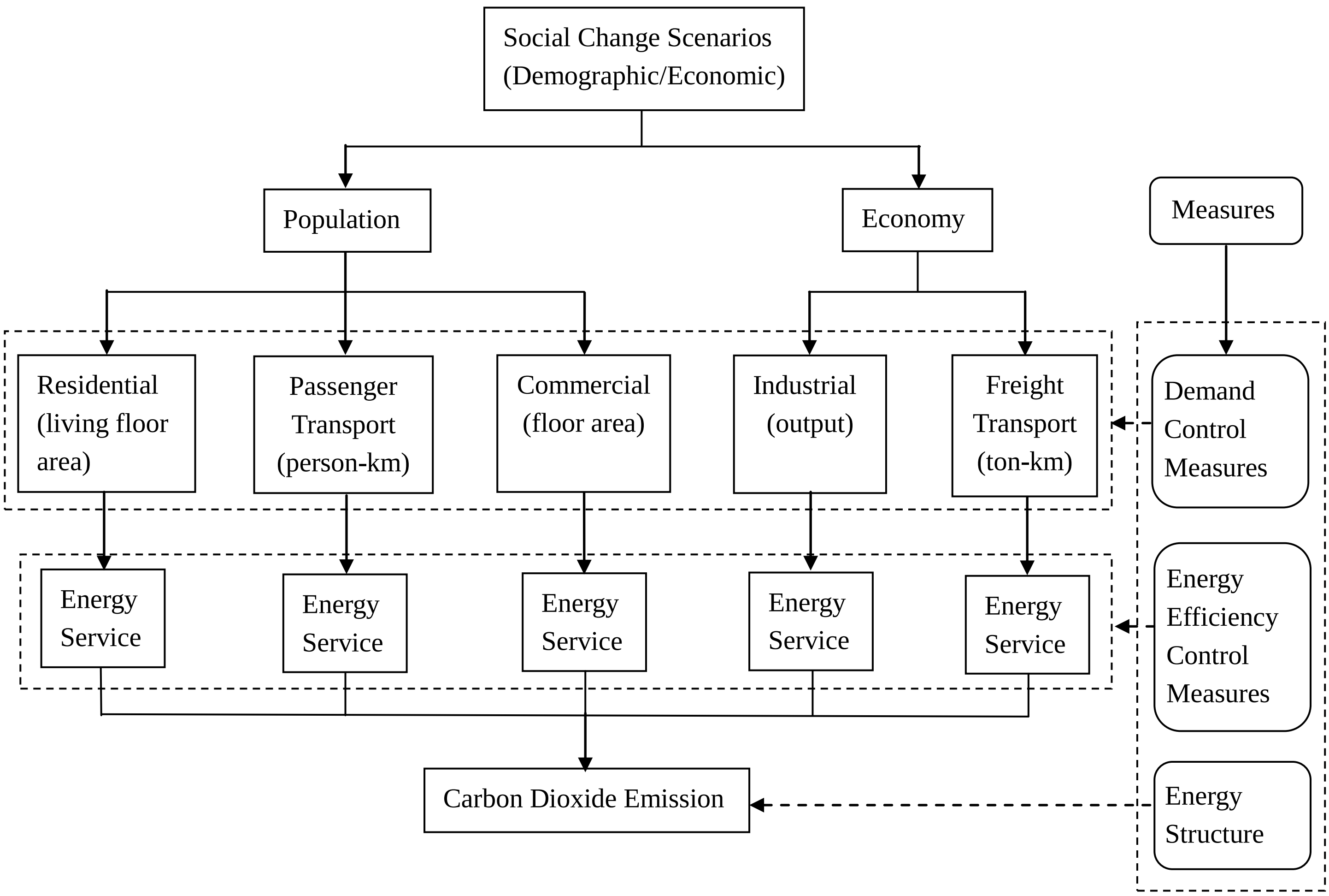

Figure 1- 1 Framework of Scenario Analysis

From the above framework, we can see that the major driving forces of carbon dioxide emission include demographic, economics and technology.

First, these driving forces do not influence the emission level of carbon dioxide separately. Demographic development interacts with social and economic development. Fertility and mortality trends depend on education, income, social norms, and health provision which in turn determine the size and age composition of the population (Nakicenovic and Swart, 2000). Many of these factors combined are recognized as necessary to explain long-run productivity, economic growth and economic structure (Barro, 1997). There are also some links from demography and the economy to emissions. Demographic change may not only affect macro variables such as aggregate consumption, but also influence the composition of consumption which affects energy use. For example, rural people who migrate to urban area will consume more energy-intensive goods. Old people consume more heat energy than young people because they tend to be more sensitive to cold, while they consume less gasoline because they use cars less frequently. Thus people with different income and preferences use different types of energy which affect the emission level.

Second, economic growth experiences several stages, which affect energy demand. According to Rostovian take-off model, economic modernization occurs in five basic stages: The first stage is traditional society, in which agriculture is predominant and the productivity is low. The second one is preconditions for take-off. As incomes, savings and investment grow, entrepreneurs emerge. The third is take-off. This stage is to describe the process of traditional to a modern economy. The share of investment in national income rises and the manufacturing sector grows at a high speed. Workers migrate from the agricultural sector to the manufacturing sector. The fourth is drive to maturity. The economy is diversifying and producing a wide range of goods and services. Industrialization and catch-up to the ‘productivity frontiers’ prevail in the industrialized countries (Nakicenovic and Swart, 2000). The fifth is age of high mass consumption in which tertiary industry rises to predominance. Under different economic development process, energy demand is different. From traditional society to industrialization, energy is mainly used by industrial sector. From industrialization to post-industrial society, more energy is consumed by transportation sector and commercial sector. Besides, with the improvement of life standard and urbanization, more energy is used in residential sector.

The above is based on the analysis of energy demand. Although energy demand control is an important measure to mitigate carbon dioxide emission, the increase of energy demand may be unavoidable during the period of industrialization and urbanization. Another important factor is technology improvement which has an impact on energy efficiency and energy structure. Technology improvement can increase energy efficiency. Increased energy efficiency can be defined as producing the same output with lower energy input without increasing the use of other factors of production. Thus we assume that if energy efficiency improvement measures have been taken and the price of energy does not increase, the cost of energy input will be lower. On the other hand, technology improvement can reduce the cost of non-fossil fuel energy such as hydropower, nuclear power, solar and wind. Lowering the price of non-fossil fuel energy will encourage profit maximizing firms to increase the use of this type of energy and decrease the use of fossil fuel, which improve energy structure and in turn reduce carbon dioxide emission.

1.4 Structure of the Thesis

The structure of the thesis is as follows. Chapter 2 analyzes the developing progress and current situation in Shanghai by economic and social characteristic, population, energy consumption, carbon dioxide emission and so on. Chapter 3 determines objectives, describes the scenarios and sets detailed value of the parameters. Chapter 4 is the main results of the estimation of final energy consumption and carbon dioxide emission. Chapter 5 discusses the countermeasures to create a low carbon economy, such as enhancing energy efficiency, optimizing energy structure, adjusting industrial structure, setting efficient and fast transportation system, developing energy-saving technologies. Chapter 5 makes a conclusion of the main results and countermeasure and proposes the further research directions.

2、The Overview of Shanghai

2.1 Economic Development

During thirty years' reform and opening up, Shanghai's economy has experienced a sustained and stable growth. From 1978 to 2008, Shanghai GDP increased from 272.81 to 15046.45 (100 million yuan) and the annual average growth rate was about 10.5%. Especially after the 1990s, the average growth rate of GDP during the "eighth five-year plan (1991-1995)", "ninth five-year plan (1996-2000)" and "tenth five-year plan (2001-2005)" was 13.2%, 11.5% and 11.9% respectively. And from 2006 to 2009, the average growth rate of GDP has reached 11.5%. In 2008, Shanghai's land area was 6340.50 square km which occupied 0.067% of total land area in China, while Shanghai accounted for 4.6%[2] of China's total GDP.

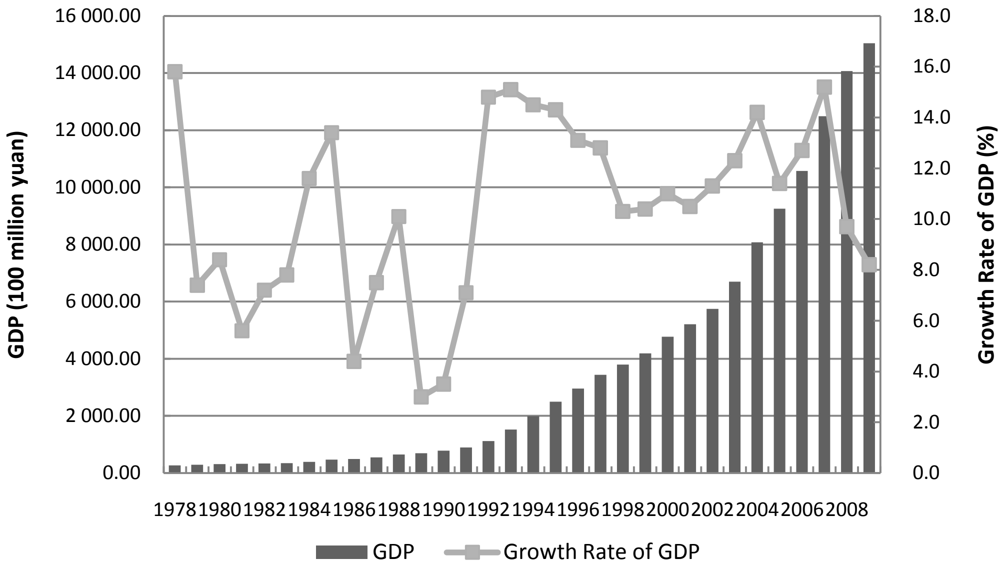

Figure 2- 1 GDP and GDP Growth Rate of Shanghai (1978-2009)

Data Source: Shanghai Statistical Yearbook 2010

In 1978, Shanghai's GDP per capita was 2485 yuan while in 2009 it rose to 78989 yuan, which was higher than GDP per capita of China (25125 yuan) at the same time. And its annual average growth rate was 12.06%. If calculated by PPP (Purchasing Power Parity), Shanghai's GDP per capita was about 21064 US dollars in 2009, which was equivalent to the level of main developed countries in the 1990s (see the table 2-1).

[2] In 2008, Shanghai's GDP is 14069.87 million yuan and GDP of the whole country is 302853.4 million yuan.

Table 2- 1 GDP per Capita by PPP in Some Developed Countries

Country	Year	GDP per Capita by PPP (current international $)
Australia	1996	21920
Canada	1994	21808
France	1997	21746
Germany	1994	21665
Japan	1993	21258
Singapore	1993	21258
United Kingdom	1997	22421
United States	1989	22038

Data Source: World Bank

From the perspective of industrial development, the annual average growth rate of primary, second and tertiary industry was 2.6%, 9.9% and 12.2% during the period between 1978 and 2009. Under the industrial policy of 'tertiary, second and primary' in the 1990s, tertiary industry's share of GDP was 30.9% in 1990 and increased to 52.1% in 2000. The contribution rate of economic growth was about 56.25%. The rapid growth of tertiary industry improved industrial structure in Shanghai.

In view of the development trend at home and abroad, Shanghai government decided to reestablish 'New Heights of Industry' by the end of 1998. After 1999, Shanghai government increased the investment in industrial sector, which led to a rapid growth of industry. The annual average growth rate of industry was 13.8% between 2001 and 2005 which was higher than that of tertiary industry[3] during the same period, and tertiary industry's average share of GDP was 51.7%. Under the combination of demand stimulation and government's investment impulsion, heavy industry (such as steel and building materials) and real estate increased dramatically, which slowed down the growth speed of tertiary industry. The structure of industry has not been improved significantly.

[3] The annual average growth rate of tertiary industry was 11.2% during the period of 2001 and 2005.

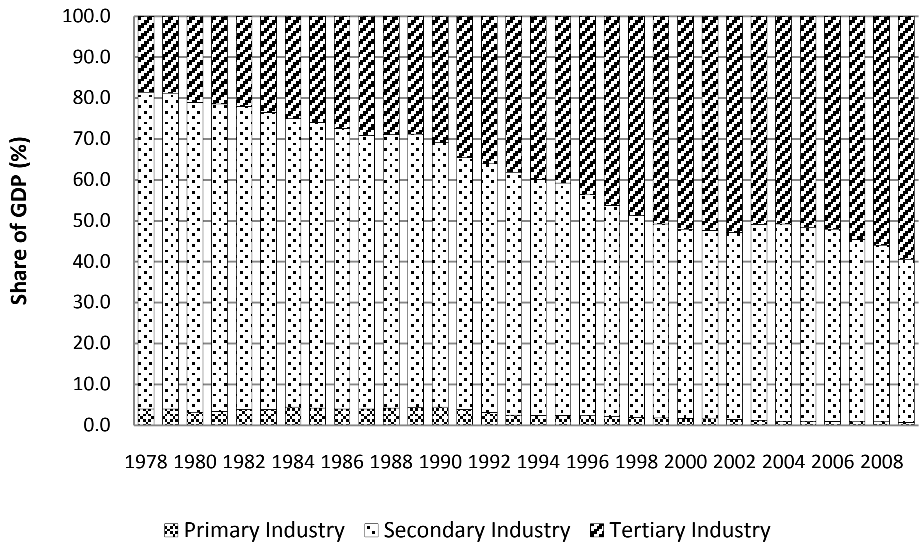

Figure 2- 2 Share of Primary, Secondary and Tertiary Industry of GDP (1978-2009)

Data Source: Shanghai Statistical Yearbook 2010

From 2006 to 2009, under the policy of 'Energy Saving and Emission Reduction', Shanghai's industrial structure has been improved further. The average growth rate of tertiary industry went up to 14.08%. Due to the elimination of backward industry, secondary industry was on the slow rise. The annual average growth rate was 8.63%, which was lower than the level between 2001 and 2005.

Table 2- 2 Growth Rate of Primary, Secondary and Tertiary Industry in Shanghai (1981-2009)

	Primary Industry	Secondary Industry	Tertiary Industry
1981-1985	5.90%	8.38%	12.30%
1986-1990	1.26%	5.04%	7.98%
1991-1995	1.48%	13.96%	12.84%
1996-2000	3.38%	9.74 %	15.54%
2001-2005	-1.28%	13.12%	11.24%
2006-2009	0.60%	8.63%	14.08%

Data Source: Shanghai Statistical Yearbook 2010

With rapid economic growth, Shanghai's life quality has been improved significantly. From 1990 to 2009, average per capita disposable income of urban households increased from 2183 yuan to 28838 yuan, living consumption expenditure increased from 1937 yuan to 20992 yuan, and the Engel coefficient decreased from 56.5% to 35.0%; average per capita rural disposable income of rural households rose from 1665 yuan to 12324 yuan, living consumption expenditure rose from 1262 yuan to 9804 yuan and the Engel coefficient declined from 46.4% to 37.1%. However, since the mid 1990s the contribution rate of consumption was around 50%, which was different from the developed countries[4]. Economic growth mode driven by consumption hasn't been established.

2.2 Demographic Development

The resident population in 1990 was 13.34 million persons while it was 19.21 million persons in 2009. The annual average growth rate was 1.94%. The registered population hasn't changed a lot during the period between 1990 and 2009. So the increase of resident population was mainly caused by the floating population.

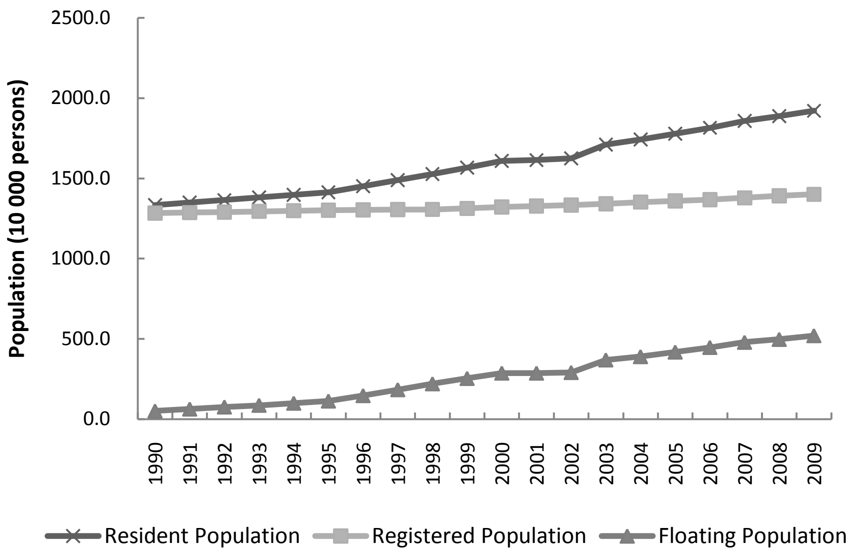

Figure 2- 3 Population in Shanghai (1990-2009)

Data Source: Shanghai Statistical Yearbook 2010

In 1978, Shanghai urbanization rate reached 58.8%, which was much higher than that of China in 2008 (45.68%). In 2003 urbanization rate has exceeded 80%. From the figure 2-4 we can see that urbanization rate of 2004 and 2005 experience a rapid growth.

[4] In general, the contrition rate of consumption in developed countries has reached 70%.

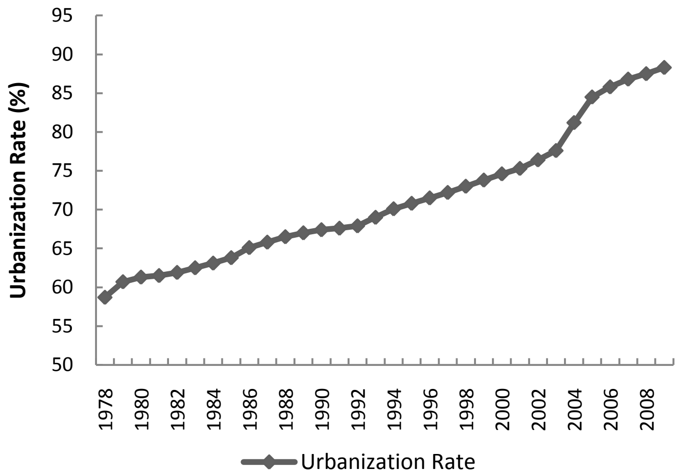

Figure 2- 4 Urbanization Rate in Shanghai (1978-2009)

Data Source: Shanghai Statistical Yearbook 2010

As early as 1979, the proportion of the aging population reached 10.07% of the registered population in Shanghai, which showed that the age structure of Shanghai had entered the aging society. Afterwards, the aging population was on the rise (see Table 2-3). In 2009, the population over 65 was 2.21 million, which accounted for 15.8% of the registered population. The aging level is close to that of developed countries.

Table 2- 3 The Aging Process of Registered Population in Shanghai (1996-2009)

Year	Population above 65 (10 000 person)	Population above 80 (10 000 person)	The percentage of the population above 65（%）	The percentage of the population above 80（%）
1996	162.06	24.76	12.4	1.9
1997	162.06	24.76	12.8	1.9
1998	174.16	26.58	13.3	2
1999	181.41	28.49	13.8	2.2
2000	186.53	29.89	14.2	2.3
2001	192.52	32.91	14.5	2.5
2002	195.70	35.28	14.7	2.6
2003	199.49	37.62	14.9	2.8
2004	201.06	40.7	14.9	3.0
2005	203.67	43.77	15.0	3.2
2006	207.58	46.78	15.2	3.4
2007	211.18	50.24	15.3	3.6
2008	214.5	53.44	15.4	3.8
2009	221.0	56.65	15.8	4.0

Data Source: Information of Shanghai’s Aging Population and Undertakings for the Aged (1996-2009)

However, it is not reasonable to calculate the proportion of aging population based on the registered population. Since the 1980s, the floating population was on the rise from several hundred thousand persons to over five million persons in 2009. Large amount of young labors immigrated to Shanghai and most of them have resided in Shanghai. If the percentage of the population over 65 is calculated based on the resident population, then it was 11.5% in 2009. Thus the level of aging is not so high in Shanghai. As an open metropolis, Shanghai has the condition to attract more young people to mitigate the consequences of aging. However, it may also generate the expansion of population. Therefore, it is important to trade off the degree of aging and population scale.

2.3 Energy

2.3.1 Energy Consumption

With rapid economic growth and the improvement of living standard, energy consumption is increasing significantly in Shanghai. The total primary energy consumption increased from 25.42 million tons SCE in 1985 to 103.15 million tons SCE in 2008. The average growth rate was 6.28%.

From the perspective of final energy consumption, industry has a large proportion. Although industrial final energy consumption occupied 77.73% in 1985 and decreased to 56.76% in 2008, the amount was still large. In 2008, industrial final energy consumption was 54.16 million tons SCE. Energy consumption in tertiary industry increased most rapidly. In 2008, the energy consumption for other services was over twenty times higher than the level of 1985 and that for transportation, storage, post and communication was more than nine times. Besides, energy consumption for construction and households also increased considerably, which was related to the growth of infrastructure construction, the improvement of life standard and the rising of consumption level.

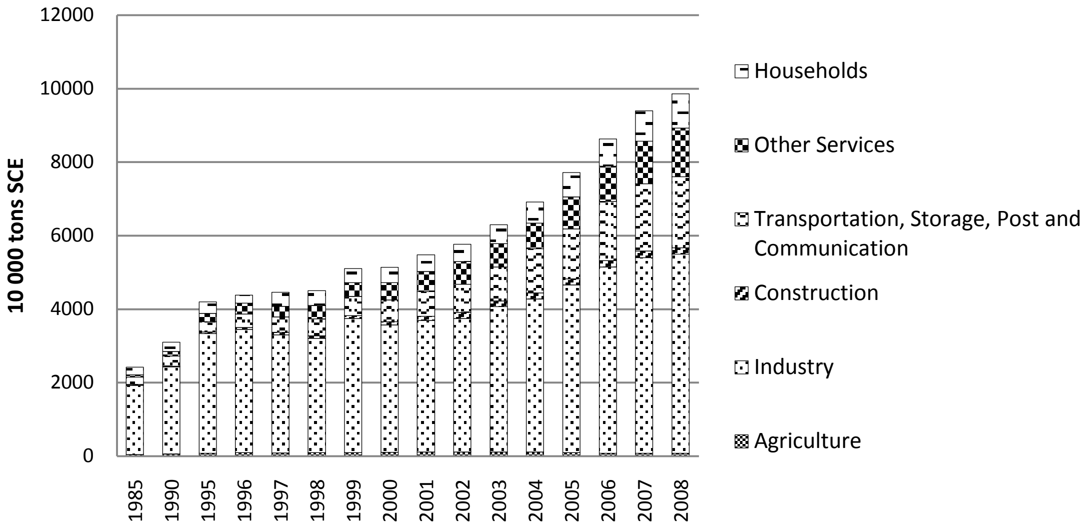

Figure 2- 5 Main Years' Energy Consumption by Sectors in Shanghai

Data Source: China Energy Statistical Yearbook, and Shanghai Statistical Yearbook on Industry, Energy and Transport

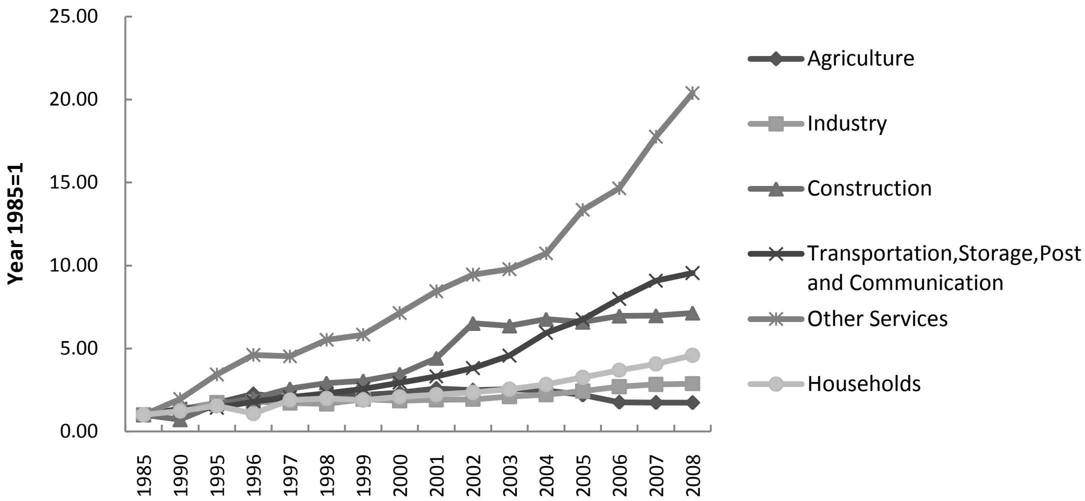

Figure 2- 6 Main Years' Growth Rate of Energy Consumption by Sectors in Shanghai

Data Source: China Energy Statistical Yearbook, and Shanghai Statistical Yearbook on Industry, Energy and Transport

Energy consumption is in connection with industrial structure. From 1990 to 2008, elasticity coefficients of energy consumption and electricity consumption[5] firstly decreased

[5] Elasticity coefficient of energy consumption is equal to growth rate of energy consumption divided by that of GDP. And

and then increased. Elasticity coefficients of energy consumption declined from 1.06 in 1990 to 0.23 in 1998 and then rose to 0.81 in 2005, finally declined to 0.58 in 2008. The tendency is consistent with the characteristic of Shanghai industrial development. From 1990 to 1998, Shanghai tertiary industry was on a rapid growth, and elasticity coefficients of energy consumption and electricity consumption showed the declining tendency. However, after the decision of reestablishing 'New Heights of Industry', elasticity coefficients were on the fluctuated rise. Elasticity coefficients began to decline until 'the 11th five-year plan' proposed the requirement of saving energy and reducing emission. Therefore, heavy industry has a determined impact on Shanghai's energy consumption trend.

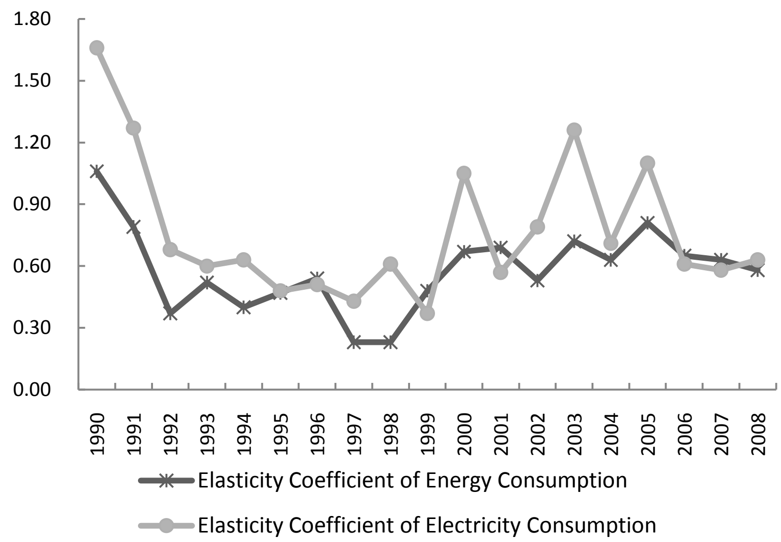

Figure 2- 7 Elasticity Coefficients of Energy Consumption and Electricity Consumption

Data Source: Shanghai Statistical Yearbook, and Shanghai Statistical Yearbook on Industry, Energy and Transport

From the figure 2-7, we can find that elasticity coefficients of energy consumption are consistent with the growth of secondary industry, mainly because energy consumption in secondary industry always has a large share of total energy consumption.

2.3.2 Energy Structure

Shanghai's energy structure is on the gradual transformation process. In 1995 coal consumption was 32.10 million tons SCE, which accounted for 72.4% of total energy consumption; in 2008, coal consumption was 45.47 million tons SCE and the proportion

elasticity coefficient of electricity consumption is equal to growth rate of electricity consumption divided by that of GDP.

decreased to 44.28%. The consumption of coal is mainly used by electric power sector, metallurgy sector, chemical sector, industrial sector and business.

In 2008, end-use electricity consumption reached 107.868 TWh which was 2.8 times larger than that of 1995. A part of electricity is generated by other provinces in China, which is called electricity outside Shanghai for short. Electricity outside Shanghai includes coal-fired power, hydropower and nuclear power, but before 2008 there were no hydropower and nuclear power was used in Shanghai. Due to the rapid growth of electricity consumption, since 2002 the share of electricity outside Shanghai increased drastically. In 2008, the share of electricity outside Shanghai occupied nearly 11% of total final energy consumption.

Because of the increase of energy consumption in transportation sector, oil consumption was on the rise, from 12.31 million tons SCE in 1995 to 42.21 million tons SCE in 2008. And the proportion went up from 27.80 % to 44.11%. Natural gas was introduced to Shanghai in 1999, mainly used by industrial sector and residential sector. Although the growth speed was quick, the share of natural gas was still small. In 2008, the consumption of natural gas was 3 billion m^3 and the proportion was only about 4% of total energy consumption.

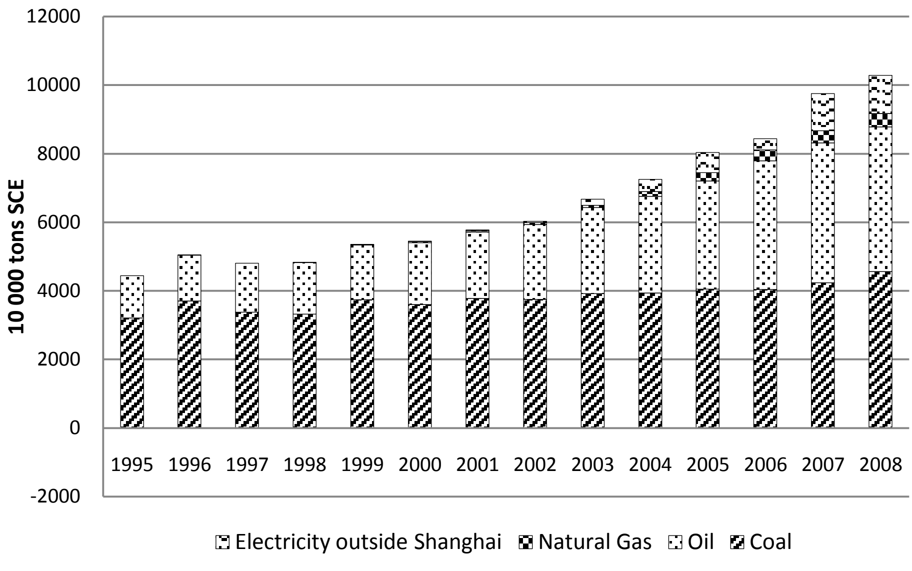

Figure 2- 8 Shanghai's Energy Structure (1995-2008)

Data Source: China Energy Statistical Yearbook, Shanghai Statistical Yearbook on Industry, Energy and Transport

2.3.3 Carbon Dioxide Emission

Since energy consumption increases dramatically and it is mainly dependent on coal, the emission level of carbon dioxide is on the rise. According to Shanghai's energy balance table and the IPCC guideline (2006), carbon dioxide emission is assessed from 2000 to 2008 by the following equations (detailed calculations see Appendix I):

$$E = \sum_i A_i \times EF_i \qquad (1)$$

$$EF_i = NCV_i \times C_i \times O_i \times 44 \div 12 \qquad (2)$$

where A_i is the amount of consumption fuel i, EF_i is emission factor, NCV_i is net calorific value of fuel i (TJ/Gg), C_i is carbon content (kg/GJ) and O_i is carbon oxidation rate of fuel i.

By estimation, in 2008 total emission level of carbon dioxide emission of energy consumption was about 1.8 times higher than that of 2000, and the annual growth rate was 7.69%.

From the perspective of the structure of carbon dioxide emission, total emission level was 2.11 (100 million tons) in 2005. The proportion of carbon dioxide emission related to coal was 58.49% while coal accounts for 50.41% of total primary energy consumption.

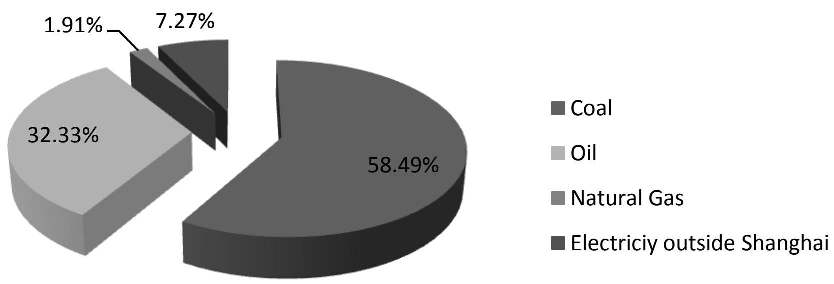

Figure 2- 9 Structure of Shanghai's Carbon Dioxide Emission (2005)

Except the total emission of carbon dioxide is increasing by a large margin, carbon dioxide emission per capita in Shanghai has exceeded the level in some developed countries (see table 2-4). Although carbon dioxide emission per capita in Shanghai is lower than the level in

Australia, Canada and United States, it has been higher than the level in the United Kingdom, Germany, Japan and France. Meanwhile, it is over two times higher than the average level of China and the world.

Table 2- 4 Comparison of Carbon Dioxide Emission per Capita between Shanghai and some Developed Countries in 2008

Country	Carbon Dioxide Emission per capita (tCO_2/person)
Australia	18.48
Canada	16.53
United Kingdom	8.32
Germany	9.79
Japan	9.02
France	5.74
United States	18.38
India	1.25
World	4.39
China	4.92
Shanghai	13.76

Data Source: IEA, CO2 Emissions from Fuel Combustion Highlights 2010

The high emission level of carbon dioxide per capita in Shanghai is related to energy structure—coal occupied a large share of primary energy consumption. Nevertheless, it cannot be ignored that energy consumption per capita is also increasing dramatically. In 2008, Shanghai's energy consumption per capita was 5.22 tce[6], which was 2.6 times higher than the average level of the whole country. Shanghai's energy consumption per capita and carbon dioxide emission per capita has surpassed the level of some developed countries. However, large amount of energy consumption is not mainly used by improving living standard and enhancing welfare, but by the industrial sector. In 2008, per capita energy consumption for households in Shanghai was 0.49 tce, which was less than half of the level in Tokyo.

2.4 Conclusion

With the rapid economic growth, it is obvious that Shanghai has become an economic center of China, even of East Asian. More and more attention has been paid to Shanghai all

[6] It is calculated by resident population.

over the world. The direction of Shanghai's future development is to construct 'Four Centers'—international economic, trade, finance and shipping centers and to become an international metropolis such as New York, London and Paris. Under this condition, Shanghai has to control and reduce the emission level of carbon dioxide.

Economic growth and population expansion are two major drives of carbon dioxide emission. For population, it is important to trade off between population scale and aging. For economic development, it is necessary for Shanghai to transform economic structure from secondary industry to tertiary industry and transform social development from industrialization to post-industrialization. If Shanghai only focuses on the speed of economic growth and ignores the quality of economic growth, it won't become an international metropolis in the future.

3、Scenario Analysis of Low Carbon Society in Shanghai

3.1 Scenario Setting

According to Shanghai economic and social development and the policy of saving energy and reducing emissions, this thesis sets up four scenarios: Business As Usual (BAU) scenario, transformation scenario, moderate intervention scenario and strong intervention scenario. The base year is 2005 and the target year is 2020. Low carbon target is to reduce carbon dioxide emissions per unit of GDP in 2020 by 40%-45% compared with the level of 2005.

- BAU (business as usual) Scenario: This scenario is to keep economic growth at a high speed. Assume that annual economic growth rate will remain 9.00% from 2010 to 2020, and final energy consumption per unit of GDP will decrease by 1.50% annually, from 0.83 tce/10 000 yuan in 2008 to 0.69 tce/10 000 yuan. According to the above assumptions, energy consumption in 2020 will reach 2.29 (100 million tons) and energy consumption per capita will be 9.91 tce/person.
- Transformation Scenario: Under the current policy and without introducing countermeasures, social and economic development transforms from industrialization to post-industrialization, and economic structure transforms from simultaneously developing secondary and tertiary industry to mainly developing tertiary industry.
- Moderate Intervention Scenario: Based on the transformation scenario, a lot of energy efficiency control measures and energy structure improvement measures have been taken and certain energy demand control measures have been taken moderately in order to achieve the target.
- Strong Intervention Scenario: Lots of energy demand control measures, energy efficiency control measures and energy structure improvement measures have been taken strongly in order to achieve the target.

3.2 Population

3.2.1 Population Regression

This thesis will use a linear regression to predict Shanghai's resident population from 2010 to 2020.

Firstly, the factors directly related to population are birth rate and death rate.

$$P_t = \alpha_0 + \alpha_1 BR_t + \alpha_2 DR_t + \delta_t \qquad \text{(1-a)}$$

where P denotes resident population, BR denotes birth rate and DR denotes death rate. And t denotes the year from 1990 to 2009. The regression result is as follows:

$$P_t = \underset{(1273.985)}{-1118.751} + \underset{(31.908)}{9.370} BR_t + \underset{(160.469)}{362.988} DR_t + \delta_t \qquad \text{(1-b)}, \quad \bar{R}^2 = 0.1676$$

Only the coefficient of death rate (DR) is statistically significant at 5% level and $\bar{R}^2$ is low (0.1676). The problem of the regression is omitted bias. Total fertility rate (TFR)[7] is also an important factor that will influence the population. Then the regression is changed to the new one:

$$P_t = \alpha_0 + \alpha_1 BR_t + \alpha_2 DR_t + \alpha_3 TFR_t + \delta_t \qquad \text{(2-a)}$$

And the regression result is as follows.

$$P_t = \underset{(879.08)}{1305.61} + \underset{(28.41)}{126.59} BR_t + \underset{(103.06)}{157.76} DR_t \underset{(316.75)}{-1769.56} TFR_t + \delta_t \qquad \text{(2-b)}, \quad \bar{R}^2 = 0.7002$$

We can find that the coefficients of birth rate (BR) and total fertility rate (TFR) are statistically significant at 1% level, and $\bar{R}^2$ is much larger than that of the first regression (1-b). However, this regression is still not good enough to predict the resident population in the future (2010-2020) and there also exist omitted variables.

Resident population includes registered population and floating population (i.e. people reside in Shanghai above half year). The difference between the rate of inflows and the rate of outflows of registered population is called growth rate of mechanical increase (or rate of net inflows of registered population). It can reflect the change of registered population. Another important element is percentage of floating population of registered population, which can partly represent the migration in Shanghai. Thus, growth rate of mechanical increase and the percentage of floating population are added to the following regression.

$$P_t = \alpha_0 + \alpha_1 BR_t + \alpha_2 DR_t + \alpha_3 TFR_t + \alpha_4 GRMI_t + \alpha_5 PFP_t + \delta_t \qquad \text{(3-a)}$$

where GRMI denotes growth rate of mechanical increase and PFP denotes the percentage of floating population (above half year) of registered population. Then the regression result is as follows.

[7] Total Fertility Rate is the average number of children that would be born to a woman over her "child-bearing years", which in conventional statistical usage is 15-44 or 15-49.

$$P_t = \underset{(118.094)}{965.098} + \underset{(5.271)}{29.171} BR_t + \underset{(14.593)}{33.698} DR_t - \underset{(68.497)}{171.785} TFR_t + \underset{(3.401)}{2.248} GRMI_t + \underset{(1.053)}{22.294} PFP_t + \delta_t \quad (3\text{-b}),$$

$\bar{R}^2$ =0.9946

Only the coefficient of GRMI is not statistically significant. The coefficients of BR and PFP are statistically significant at 1% level and those of DR and TFR are significant at 5% level. And $\bar{R}^2$ is 0.9946. Therefore, we will choose regression (3-b) to predict Shanghai's resident population.

The result of each regression is shown in the following table.

Table 3- 1 Results of Population Regressions

Regressor	**(1)**	**(2)**	**(3)**
BR	9.370	126.59**	29.171**
DR	362.988*	157.76	33.698*
TFR		-1769.56**	-171.785*
GRMI			2.248
PFP			22.294**
constant	-1118.851	1305.61	965.098**
F statistics	0.0817	0.0000	0.0000
R^2	0.2552	0.7476	0.9961
$\bar{R}^2$	0.1676	0.7002	0.9946

3.2.2 Assumptions and Results of Population Predict

The population in the future can be predicted by the assumptions on the trend of each variable. Figure 3-1, 3-2 and 3-3 is about the changing trend of birth rate, death rate, growth rate of mechanical increase, total fertility rate and percentage of floating population.

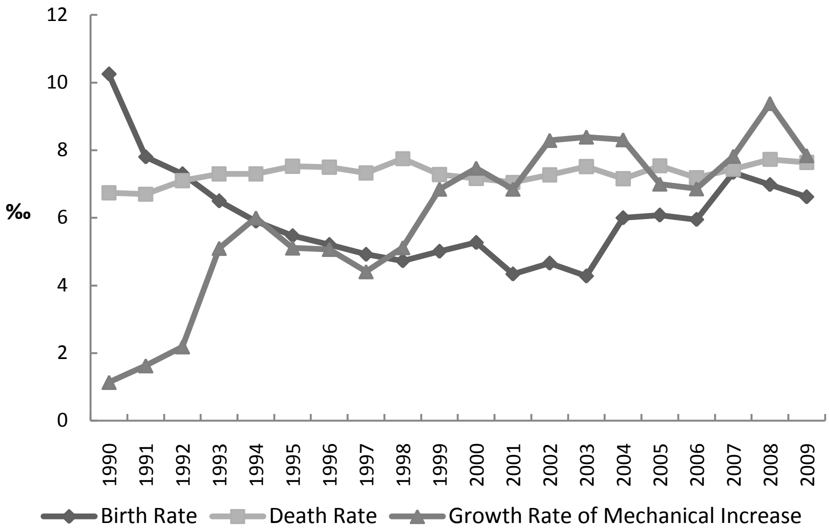

Figure 3- 1 Birth Rate, Death Rate and Growth Rate of Mechanical Increase in Shanghai (1990-2009)

Data Source: Shanghai Statistical Yearbook 2010

From the figure 3-1, we can see that birth rate decrease considerably from 10.25 ‰ in 1990 to 4.73 ‰ in 1998. After 1998, birth rate is on the fluctuated rise. So it can be assumed that birth rate still has the rising inclination with fluctuation. Death rate is relatively steady and most of them remain around 7.5 ‰. Thus, assume that from 2010 to 2020 it won't change a lot. Growth rate of mechanical increase has the rising trend and goes up and down from 1990 to 2009. Therefore, we still assume that it will increase in the near future.

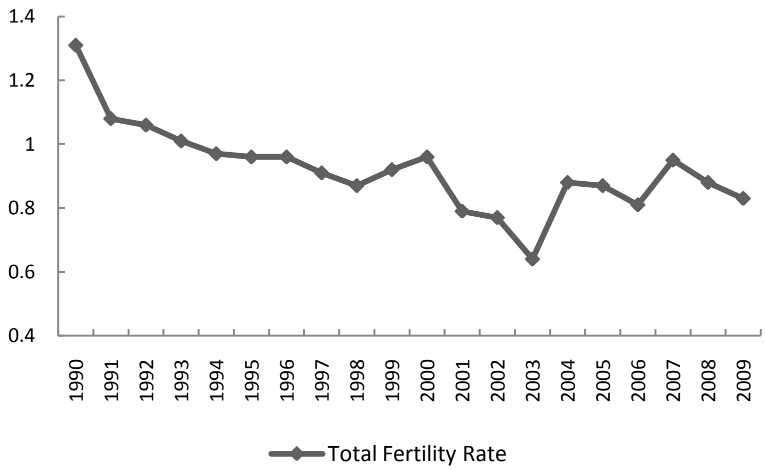

Figure 3- 2 Total Fertility Rate in Shanghai (1990-2009)

Data Source: Wang and Wei, 2009. Shanghai's Aging Peak Predict and its Countermeasures. Science Development: 38-57.

From the figure 3-2, we can find that total fertility rate has the similar tendency with birth rate. It decreases significantly from 1.31 in 1990 to 0.87 in 1998. After 1998 it fluctuates a lot, but doesn't have an obvious tendency of increasing, which differs from the tendency of birth rate at the same period. Consequently, the assumption of total fertility rate (2010-2020) is that it will have similar fluctuations of the period between 2001 and 2009.

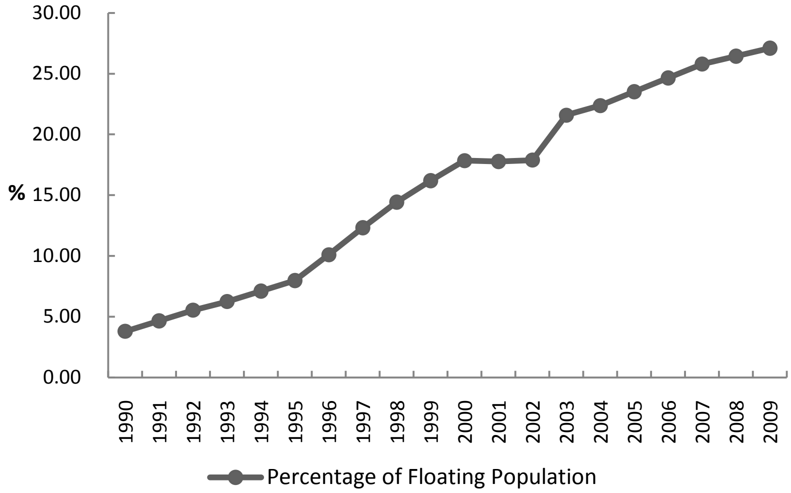

Figure 3- 3 Percentage of Floating Population of Registered Population in Shanghai (1990-2009)

Data Source: Shanghai Statistical Yearbook 2010

From the figure 3-3, it is shown that percentage of floating population is on the rise, from 3.80% in 1990 to 27.10% in 2009. In the 1990s, the growth rate of percentage of floating population is always above 10% and the highest one is 22.37% in 1991. After 2000, the annual average growth rate is 4.91%. Due to Shanghai's household registration policy, the growth rate of floating population won't increase a lot in the future.

The detailed assumptions of the changing trend of each variable are as follows (see table 3-2)

Table 3- 2 Assumptions on Growth Rate of Independent Variables in Regression (3-b)

Year	BR	DR	GR	TFR	PFP
2010	15.00%	0.31%	4.33%	10.00%	4.50%
2011	-5.00%	0.31%	4.33%	-6.00%	4.50%
2012	-5.00%	0.31%	4.33%	-6.00%	4.50%
2013	15.00%	0.31%	4.33%	10.00%	4.50%
2014	-5.00%	0.31%	4.33%	-6.00%	4.50%
2015	-5.00%	0.31%	4.33%	-6.00%	4.50%
2016	15.00%	0.31%	4.33%	10.00%	4.50%
2017	-5.00%	0.31%	4.33%	-6.00%	4.50%
2018	-5.00%	0.31%	4.33%	-6.00%	4.50%
2019	15.00%	0.31%	4.33%	10.00%	4.50%
2020	-5.00%	0.31%	4.33%	-6.00%	4.50%

According to the above assumptions, Shanghai's resident population is estimated (see table 3-3).

Table 3- 3 Shanghai's Resident Population

Year	1990	2000	2010	2015	2020
Resident Population (10 000 persons)	1334.0	1608.6	1938.3	2110.2	2317.1

3.3 Economic Development

Between 2030 and 2040, China will basically complete the process of industrialization. That is to say, China will keep a rapid economic growth during the next two decades. Afterwards, China will enter to the post-industrialization stage and the speed of economic growth will slow down. Shanghai is ahead of the process about ten or twenty years, and currently it is on the later stage of industrialization and on the threshold of post-industrialization stage.

According to developed countries' experience and combined with the judgment that Shanghai is in the process of transformation to post-industrial society, this thesis predict GDP and growth rate of GDP by the trend of future consumption (final consumption), investment (gross capital formation), import and export (net outflows of goods and services) under three scenarios (i.e. transformation scenario, moderate intervention and strong intervention scenario)

3.3.1 Changing Trend of Driving Factors of GDP in Shanghai

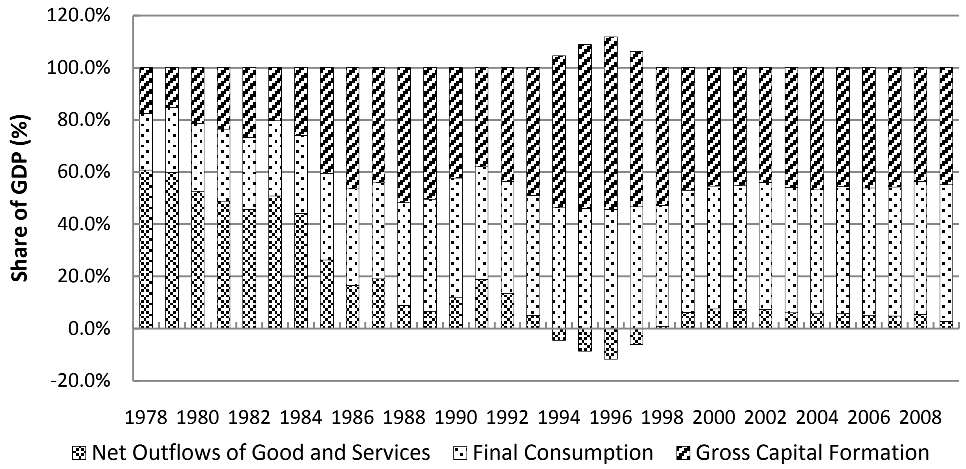

Figure 3- 4 Structure of Shanghai's GDP by Expenditure Approach (1978-2009)

Data Source: Shanghai Statistical Yearbook 2010

(Note: GDP, final consumption, gross capital formation and the net outflows of goods and services are calculated at the constant price of 2000.)

From the figure 3-4, we can find that from the end of the 1970s to the mid of the 1980s a large share of GDP was used to support the whole nation. In 1978, the share of net outflows of GDP was 60.8%, that of final consumption was 21.7% and that of gross capital formation was 17.6%. In 1978, final consumption was only 13.7 billion yuan (at the constant price of 2000). Afterwards, final consumption increased steadily and its share of GDP was also on the rise. In 2009, Shanghai's final consumption was 675.6 billion yuan which was nearly fifty times larger than that of 1978, and the average annual growth rate was 13.51%. The share of final consumption of GDP rose from 21.6% in 1978 to 52.3% in 2009. Figure 3-5 is about the share of final consumption in some developed countries. It is shown that from 1971 to 2009 the share of final consumption went up and down, but it still has the rising trend. In 2009, the proportion of final consumption in most developed countries is over 70%. Thus, according to these developed countries' experience, the share of final consumption of GDP in Shanghai will be nearly 70% in 2020.

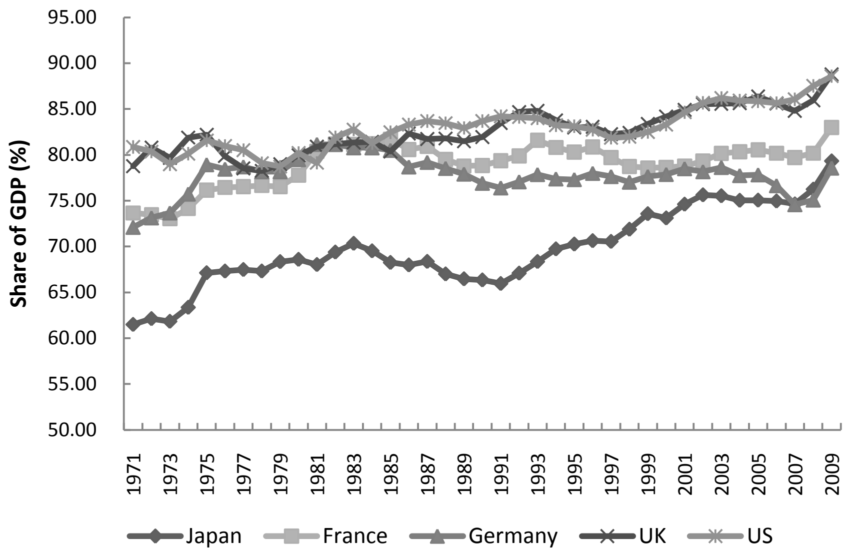

Figure 3- 5 Share of Final Consumption of GDP in Some Developed Countries (1971-2009)

Data Source: World Bank

The growth rate of final consumption was relatively steady, especially after 1994. Expect the growth rate in 1998 reduced to 9.6% due to Asian financial crisis, other years' growth rate was between 11% and 16%. The average growth rate of final consumption was 12.9% during the period between 1994 and 2009. Final consumption will become the main drive of Shanghai's economic development. If there doesn't exist the expansion of population in Shanghai, the growth rate of final consumption will be stable. After 2000, most pulling rate of final consumption to GDP[8] is between 5% and 7%.

Table 3- 4 Pulling Rate of Final Consumption, Gross Capital Formation and Net Outflows to GDP (1981-2009)

Period	GDP Growth Rate	Pulling Rate		
		Final Consumption	Gross Capital Formation	Net Outflows
1981-1985	9.11%	4.18%	6.49%	-1.56%
1986-1990	5.71%	4.78%	3.09%	-2.17%
1991-1995	13.17%	5.96%	10.87%	-3.67%
1996-2000	11.52%	5.55%	2.88%	3.09%
2001-2005	11.94%	6.01%	5.48%	0.45%
2006-2009	11.45%	6.70%	5.02%	-0.27%

Data Source: Shanghai Statistical Yearbook 2010

[8] Contribution rate of final consumption to GDP equals to the increase of final consumption divided by that of GDP. And pulling rate of final consumption to GDP means that contribution rate of final consumption multiplies the growth rate of GDP.

Since 1978, gross capital formation increased drastically and its annual average growth rate was 15.09% from 1978 to 2009. Compared to the steady growth of final consumption, the growth of gross capital formation fluctuated a lot. In 1985 Gross capital formation increased by 76.7% compared to that of 1984, and in 1996 the share of gross capital formation of GDP was 66.2%. After 2000, the growth speed of gross capital formation slowed down and the annual average growth rate was 11.2%. The share of gross capital formation was around 45%. From the perspective of Shanghai's development history, investment pulling to GDP has the feature of economic cycle. For instance, between 1991 and 1995, the open-up policy of Pudong district, the reconstruction of old city and infrastructure construction led to the pulling rate of gross capital formation over 10%. During the period of 1996 and 2000, economic development experienced some adjustments and the average pulling rate declined to 2.88%. After 2000, reestablishing 'New Heights of Industry' and investments to the World Exposition 2010 makes gross capital formation increased again and its pulling rate rose to above 5% (see table 3-4).

From the above analysis, the growth rate of gross capital formation will be on the decline and its pulling rate to GDP will also decrease. The share of gross rate will also decline based on the developed countries' experience. From the figure 3-6, except the United Kingdom and the United States, the share of gross capital formation of GDP is on a slow and fluctuated decline. After the economic development reaches maturity, the shares of gross capital in these developed countries are between 15% and 30%. Thus, the share of gross capital formation in Shanghai will be on the slow decline and will reach nearly 30% in the near future.

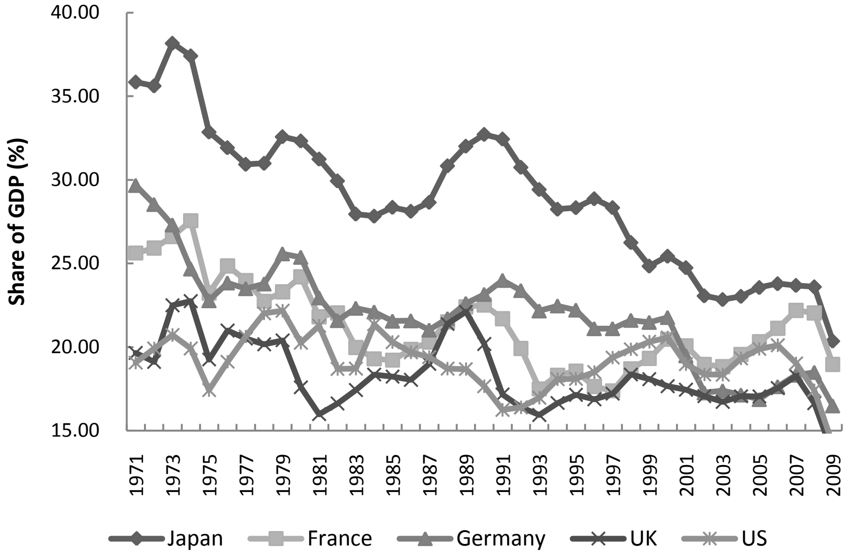

Figure 3- 6 Share of Gross Capital Formation of GDP in Some Developed Countries (1971-2009)

Data Source: World Bank

Net outflows of goods and services haven't changed a lot, from 38.33 billion yuan in 1978 to 63.93 billion yuan in 2008. However, the growth rate of net outflows had the largest fluctuation, especially in the 1990s. The highest growth was seven times, and the lowest is two times less. From 1978 to 1996, net outflows fluctuated a lot, but in general it was declining during the fluctuation. Furthermore, between 1994 and 1997, there existed the stage of net inflows. After 1997, net outflows began to increase again. The share of net outflows of GDP was always decreasing, from 60.8% in 1978 to 2.7% in 2009. That is to say, the contribution of net outflows to GDP becomes smaller and smaller.

3.3.2 Scenario Analysis of Economic Development in Shanghai

From the above analysis, we can find that with the expansion of economic scale, maturity of economic development and the increase of GDP, the growth rate of final consumption, gross capital formation and net outflows will decrease gradually. As a major drive, the share of final consumption of GDP will increase.

3.3.2.1 Transformation Scenario

(1) Scenario Description

Assume that from 2010 to 2020 heavy industry won't increase and the existing heavy industry won’t decrease but can be renewed. Economic growth will mainly rely on service sector and advancing manufacturing. On the other hand, the growth rate of investment will decline and its pulling to GDP will be weakened. Consumption will still be on a rapid growth and become the main drive of GDP growth. According to the assumptions on growth rate of final consumption, gross capital formation and net outflows (see table 3-5), we can estimate GDP and its growth rate in the next decade. The calculations of growth rate and share of primary, secondary and tertiary industry are illustrated in Appendix II.

Table 3- 5 Assumptions on Growth Rate of Driving Factors of GDP (Transformation Scenario)

	Final Consumption	Gross Capital Formation	Net Outflows of Goods and Services
2009-2010	11.00%	7.50%	10.00%
2011-2015	10.00%	4.50%	5.00%
2015-2020	9.00%	3.50%	4.00%

Another important assumption is about energy consumption by industry. The figure 3-7 is energy consumption per unit of value added of primary, secondary and tertiary industry.

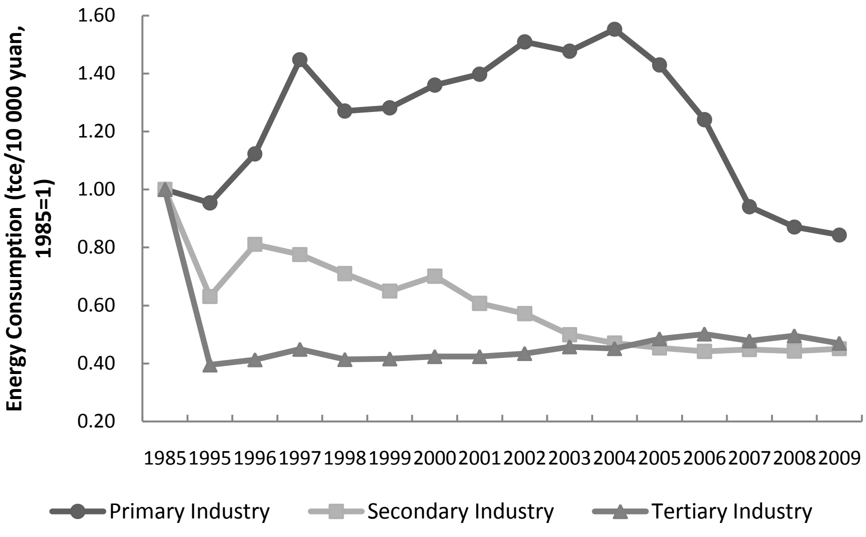

Figure 3- 7 Energy Consumption per Unit of Value Added of Primary, Secondary and Tertiary Industry (1995-2009)

Data Source: Shanghai Statistical Yearbook 2010, China Energy Statistical Yearbook, and Shanghai Statistical Yearbook on Industry, Energy and Transport

From 2004 to 2009, energy consumption per unit of primary industry was on the decline.

But during the period between 2010 and 2020 it will increase due to the decrease of agriculture labors. Assume that energy consumption per unit of value added of primary industry will increase by 1.5% annually from 2010 to 2020. From the figure 3-7, we can see that energy consumption per unit of secondary industry had the declining trend from 1985 to 2009. Since industrial structure and energy efficiency is improved by technology development, energy consumption per unit of secondary industry will decline further. Assume that energy consumption per unit of value added of secondary industry will decrease by 2.0% annually from 2010 to 2015 and by 1.5% from 2016-2020. Energy consumption of tertiary industry is classified as energy consumption of public buildings and transportation.

(2) Scenario Parameters

According to the above assumptions, the results are illustrated in the following table (see table 3-6, 3-7)

Table 3- 6 Growth Rates of GDP, Primary Industry, Secondary Industry and Tertiary Industry (Transformation Scenario)

	2000-2005	2005-2010	2010-2015	2015-2020
GDP	11.94%	10.44%	7.57%	6.91%
Primary Industry	1.35%	4.01%	1.13%	1.17%
Secondary Industry	12.51%	6.61%	5.42%	5.28%
Tertiary Industry	11.75%	14.61%	8.92%	7.79%

Table 3- 7 Share of GDP and Energy Consumption by Industry (Transformation Scenario)

	2000	2010	2015	2020
GDP (at the constant price of 2000) (100 million yuan)	4771.17	14132.60	20355.56	28428.69
Primary Industry	1.61%	0.70%	0.52%	0.39%
Secondary Industry	46.27%	38.70%	34.99%	32.41%
Tertiary Industry	52.12%	60.59%	64.49%	67.20%
Energy Consumption by Industry (tce/10 000 yuan)				
Primary Industry (1985=1)	1.36	0.90	0.97	1.04
Secondary Industry (1985=1)	0.70	0.44	0.40	0.37

3.3.2.2 Moderate Intervention Scenario

(1) Scenario Description

The economic development is the same as that under transformation scenario. The difference is energy consumption by industry.

Under moderate intervention scenario, energy consumption of primary industry will still be on the rise, but the growth rate is lower than that under transformation scenario. Assume that energy consumption per unit of primary industry will increase by 1.0% annually from 2010 to 2020. Due to the elimination of backward production capacity, the innovation of energy-saving technology, the adjustment of industrial structure and the upgrading of value added products, energy consumption of secondary industry will decline further. Assume that energy consumption per unit of secondary industry will decrease by 2.5% annually from 2010 to 2015 and by 2.0% from 2016 to 2020.

(2) Scenario Parameters

According to the above description, the change of energy consumption by industry is as follows (see table 3-8).

Table 3- 8 Energy Consumption by Industry (Moderate Intervention Scenario)

	2000	2010	2015	2020
Primary Industry (1985=1)	1.36	0.89	0.93	0.98
Secondary Industry (1985=1)	0.70	0.44	0.39	0.35

3.3.2.3 Strong Intervention Scenario

(1) Scenario Description

Assume that from 2010 to 2020 heavy industry won't increase and some old chemical industrial areas and backward heavy industries will be phased out. Under strong intervention, economic development is mainly dependent on tertiary industry and advancing manufacture. Consequently, Shanghai's economic growth rate will slow down and the growth rate of industry will decrease by a large margin. The assumptions on growth rate of final consumption, gross capital formation and net outflows are as follows.

Table 3- 9 Assumptions on Growth Rate of Driving Factors of GDP (Strong Intervention Scenario)

	Final Consumption	Gross Capital Formation	Net Outflows of Goods and Services
2009-2010	11.00%	7.50%	10.00%
2011-2015	10.00%	3.00%	4.00%
2015-2020	8.00%	2.50%	3.00%

Under strong intervention, energy consumption per unit of primary industry is assumed to increase by 1.0% annually from 2010 to 2020, which is the same as that under weak intervention scenario. For secondary industry, energy consumption per unit of its value added will decrease by 3.0% annually during the period between 2010 and 2020.

(2) Scenario Parameters

According to the above assumptions, the results are illustrated by the following table (see table 3-10, 3-11)

Table 3- 10 Growth Rates of GDP, Primary, Secondary and Tertiary Industry (Strong Intervention Scenario)

	2000-2005	2005-2010	2010-2015	2015-2020
GDP	11.94%	11.04%	6.97%	6.00%
Primary Industry	1.35%	4.01%	0.89%	0.59%
Secondary Industry	12.51%	6.61%	4.18%	3.68%
Tertiary Industry	11.75%	14.61%	8.66%	7.17%

Table 3- 11 Share of GDP and Energy Consumption by Industry (Strong Intervention Scenario)

	2000	2010	2015	2020
GDP (at the constant price of 2000) (100 million yuan)	4771.17	14132.60	19789.65	26484.43
Primary Industry	1.61%	0.70%	0.53%	0.40%
Secondary Industry	46.27%	38.70%	33.92%	30.36%
Tertiary Industry	52.12%	60.59%	65.56%	69.24%
Energy Consumption by Industry (tce/10 000 yuan)				
Primary Industry (1985=1)	1.36	0.89	0.93	0.98
Secondary Industry (1985=1)	0.70	0.44	0.38	0.32

3.4 Buildings

It can be separated into two parts—residential buildings and public buildings. Public buildings include schools, warehouses, offices, stores, hospitals, hotels, theatres and cinemas, and others. It represents energy consumption in commercial and service sector.

Because official statistics mainly focus on industrial energy consumption, energy consumption of buildings are divided and mixed in other areas. Therefore, it is necessary to calculate energy consumption of buildings.

Energy consumption of buildings includes electricity consumption and heat consumption. For residential buildings, electricity consumption means that electricity is used in households energy consumption, while heat consumption includes raw coal, gas, liquefied petroleum gas, natural gas and thermopower used in households energy consumption. For public buildings, electricity consumption means that electricity is used in tertiary industry which includes transportation, storage, post and communications, wholesale, retail sales and catering trade, and others. And heat consumption includes raw coal, gas, liquefied petroleum gas, natural gas and thermopower used in tertiary industry.

3.4.1 Current Situation

In 2008, energy consumption in buildings was 1568.9 (10 000 tons SCE) which was more than two times larger than that of 2000. Energy consumption of public buildings was 902.3 (10 000 tons SCE) while that of residential buildings was 666.6 (10 000 tons SCE). From 2000 to 2008, the annual growth rate of energy consumption in public buildings was 11.62% which is much higher than that in residential buildings (7.63%). And the annual average growth rate of energy consumption in buildings was 9.67%, which was higher than that of total energy consumption (8.51%). Thus, energy consumption in buildings has become an important factor to influence total energy consumption in Shanghai.

In 2008, the proportion of energy consumption in buildings occupied 15.92% of total energy consumption while it occupied 14.64% in 2000.

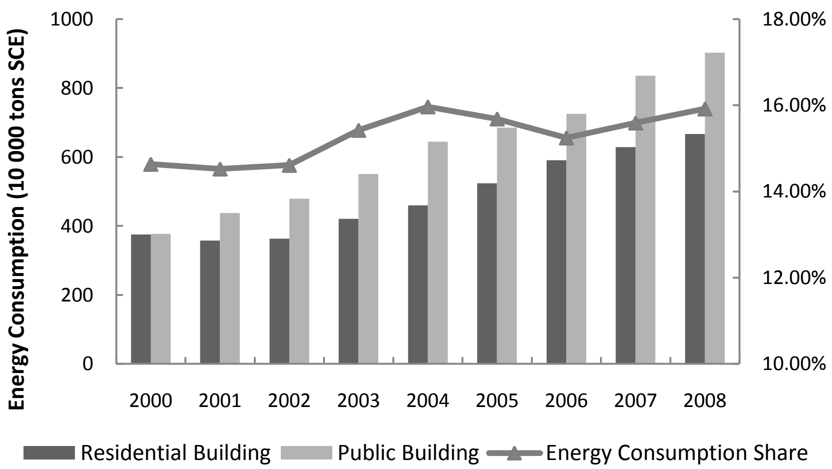

Figure 3- 8 Energy Consumption in Residential and Public Buildings and Share of Total Energy Consumption (2000-2009)

Data Source: China Energy Statistical Yearbook, and Shanghai Statistical Yearbook on Industry, Energy and Transport

In 2008, energy consumption per floor areas of public buildings was 49 $kgce/m^2$ while that of residential buildings was only 14 $kgce/m^2$ (see table 3-12).

Table 3- 12 Buildings' Energy Consumption per Floor Areas in Shanghai (2000-2008)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Public Buildings ($kgce/m^2$)	53	50	48	47	47	47	45	49	49
Residential Buildings ($kgce/m^2$)	18	15	14	14	13	14	14	15	14

From the table 3-12, we can find that energy consumption per floor areas hasn't the obvious increasing or decreasing trend. However, in the recent ten years, the floor area of residential buildings increased from 208.65 million m^2 in 2000 to 471.95 million m^2 in 2008, and the annual growth was above 30 million m^2. The floor area of public buildings increased from 76.02 m^2 in 2000 to 184.69 million m^2 in 2008, and annual growth was above 13 million m^2. Thus, the floor area of residential and public buildings will be on the rise in the future.

3.4.2 Scenario Analysis of Public and Residential Buildings

3.4.2.1 Transformation Scenario

(1) Scenario Description

According to the population predict, annual growth of Shanghai's resident population is about 0.24 million persons from 2010 to 2015. According to Shanghai Housing Construction Plan (2008-2012), 100 million m^2 residential buildings will be completed during the planning period, i.e. the annual increase of floor area is 25 million m^2. Thus, assume that the annual increase of floor area in residential buildings is 25 million m^2 from 2011 to 2015. From

2016 to 2020, the annual growth of resident population is about 0.31 million persons. Assume that the increase of floor area per person is 34 m^2. Then the increase of floor area caused by population growth is about 10 million m^2. Assume that the percentage of improving-type housing[9] is 6% and its increase of floor area per person is 10 m^2. Then the increase of floor area caused by the need of improving-type housing is approximately 11 million m^2. Thus from 2016 to 2020 the annual increase of floor area in residential buildings is assumed to be 20 million m^2. Considering employment need by population growth, the assumption on public buildings is that annual increase of floor area is about 10 million m^2 from 2010 to 2020.

Energy consumption per floor area in residential buildings will rise rapidly with the increasing need of refrigeration and heating. Assume that it will increase from 14.12 $kgce/m^2$ in 2008 to 25 $kgce/m^2$ in 2020. Although energy consumption per floor area in public buildings is at a high level, it will still be on the rise. Its annual growth rate is 5.0% from 2009 to 2010 and 3.5% from 2011 to 2020.

(2) Scenario Parameters

According to the above assumptions, the results are illustrated by the following table (see table 3-13)

Table 3- 13 Shanghai's Building Development (Transformation Scenario)

Year	2000	2010	2015	2020
Residential Buildings				
Floor Area (10 000 m^2)	20865	52711	65211	75211
Energy Consumption (kgce/m^2)	18.00	15.54	19.72	25.00
Public Buildings				
Floor Area (10 000 m^2)	7062	21315	26315	31315
Energy Consumption (kgce/m^2)	53.37	53.87	63.97	63.97

9 The definition of improving-type housing is that floor area per person is less than 33.4 square meters in Shanghai.

3.4.2.2 Moderate Intervention Scenario

(1) Scenario Description

Assume that the change of building floor area is similar to that under transformation scenario. Since the effect of thermal insulation in new buildings is better than that in the existing buildings and the energy-saving technology will be widely used in the new buildings, energy efficiency per floor area will be improved. For the new residential buildings, we assume that from 2011 to 2020 energy consumption per floor area will decrease by 3%. And every year there are 1% of the existing residential buildings[10] to be modified for energy-saving, after modification their energy consumption per floor area will reduce by 5%. The assumption on the new public buildings is that energy consumption per floor area will decrease by 3% annually. And From 2011 to 2020, every five years there are 10% of the existing public buildings[11] to be modified for energy-saving (i.e. every year there is 2% of the existing public buildings to be modified) and after modification their energy consumption per floor area will decline by 10%.

(2) Scenario Parameters

According to the above description, Shanghai's building development is shown in the following table.

Table 3- 14 Shanghai's Building Development (Moderate Intervention Scenario)

Year	2000	2010	2015	2020
Residential Buildings				
Floor Area (10 000 m^2)	20865	52711	65211	75211
Energy Consumption (kgce/ m^2)	18.00	15.54	15.87	16.67
Public Buildings				
Floor Area (10 000 m^2)	7062	21315	26315	31315
Energy Consumption (kgce/ m^2)	53.37	53.87	54.19	55.10

[10] Floor area of the existing residential buildings is based on the level of 2009, i.e. 502.11 million square meters.
[11] Floor area of the existing public buildings is based on the level of 2009, i.e.203.15 million square meters.

3.4.2.3 Strong Intervention Scenario

(1) Scenario Description

Under strong intervention, the increase of floor areas will be controlled. From 2011 to 2015, the increase of floor area in residential buildings will be 22 million square meters per year and from 2016 to 2020 the increase of floor area will be 18 million square meters per year. From 2011 to 2020, the annual average increase of floor area in public buildings is 10 million square meters. The assumptions on energy efficiency in residential and public buildings are the same as that under moderate intervention scenario.

(2) Scenario Parameters

According to the above description, Shanghai's building development is shown in the following table.

Table 3- 15 Shanghai's Building Development (Strong Intervention Scenario)

Year	2000	2010	2015	2020
Residential Buildings				
Floor Area (10 000 m^2)	20865	52711	63711	72711
Energy Consumption (kgce/ m^2)	18.00	15.54	15.77	16.47
Public Buildings				
Floor Area (10 000 m^2)	7062	21315	26315	31315
Energy Consumption (kgce/ m^2)	53.37	53.87	54.01	54.74

3.5 Transportation

The demand of transportation can be divided into passenger transport and freight transport.

3.5.1 Freight Transport

3.5.1.1 Current Situation

Urban freight transport is an important composition of transportation sector. With economic transformation in developed countries, tertiary industry accounts for a large share of GDP and freight transport has gradually become a main emitter of carbon dioxide in the urban transportation. In the near future Shanghai's freight transport will also be the main emitter in transportation sector.

Table 3- 16 Shanghai's GDP and Freight Traffic Volume (2000-2009)

Year	GDP (100 million yuan)	Freight Traffic Volume (10 000 tons)	Of which			
			Railway	Highway	Waterway	Civil Aviation
2000	4771.17	47954	1055	28369	18442	88
2001	5271.94	49545	1080	28869	19496	100
2002	5867.94	54196	1131	29759	23174	132
2003	6589.45	58669	1208	30678	26621	162
2004	7525.39	63180	1284	31554	30148	194
2005	8383.13	68741	1278	32684	34557	222
2006	9447.74	72617	1223	33799	37342	253
2007	10883.82	78108	1143	35634	41041	290
2008	11939.59	84347	985	40328	42729	305

Data Source: Shanghai Statistical Yearbook on Industry, Energy and Transport

From the table 3-16, we can find that freight traffic volume of railway is around 10 million tons. Freight traffic volume of highway and waterway increases dramatically and the growth speed of waterway is faster than that of highway. Freight traffic volume of civil aviation is also on a rapid growth.

Table 3- 17 Turnover Volume of Freight Traffic in Shanghai (2000-2008)

Year	Turnover Volume of Total Freight Traffic (100 million tons ·km)	Of Which			
		Railway	Highway	Waterway	Civil Aviation
2000	6620	122	56	6430	12
2001	6992	113	60	6808	11
2002	7472	100	65	7295	12
2003	8587	118	69	8385	15
2004	10036	42	71	9899	24
2005	12132	47	73	11986	27
2006	13837	55	80	13683	19
2007	15949	35	85	15789	40
2008	16031	29	253	15712	37

Data Source: Shanghai Statistical Yearbook on Industry, Energy and Transport

From the table 3-17, we can find that there are an important difference of the changing trend between freight traffic volume and turnover volume. That is, although freight traffic volume of railway is relatively stable, its turnover volume decreases by a large margin, from 122 (100 million tons ·km) in 2000 to 29 (100 million tons ·km) in 2008.

From the table 3-16 and 3-17, the average freight transport distance can be calculated (see table 3-18).

Table 3- 18 Average Freight Transport Distance (2000-2009)

Year	Railway (km)	Highway (km)	Waterway (km)	Civil Aviation (km)
2000	1156	20	3487	1364
2001	1046	21	3492	1100
2002	884	22	3148	909
2003	977	22	3150	926
2004	327	23	3283	1237
2005	368	22	3468	1216
2006	450	24	3664	751
2007	306	24	3847	1379
2008	294	63	3677	1213

From the table 3-18, the average freight transport distance of waterway is longest, which is around 3500 km and mainly for ocean shipping. The average freight transport distance of civil aviation remains 1100 km and most of the average distance of highway is about 23 km. The average transport distance of highway is declining dramatically, which is caused by the increasing of passenger transport and larger freight train.

Energy consumption by various means of freight transport is different (see table 3-19). In general, the highest energy consumption per turnover volume is for civil aviation and the lowest is for waterway. With the development of freight transport technology and energy-saving technology, highway has the largest potential to reduce energy consumption per turnover volume, and it is also possible for railway and civil aviation to reduce energy consumption. However, it is difficult for waterway to reduce energy consumption.

Table 3- 19 Energy Consumption per Turnover Volume in Shanghai (2008)

	Railway	Highway	Waterway	Civil Aviation
Energy Consumption per Turnover Volume （tce/ 1 million tons ·km）	45.52	83.84	4.5	518.07

Data Source: Current Situation and Development Prospect of Transportation Energy Consumption in Shanghai. Shanghai City Transportation Planning Institute.

3.5.1.2 Scenario Analysis of Freight Transport

3.5.1.2.1 Transformation Scenario

(1) Scenario Assumptions

The following assumptions are about freight transport by different modes.

Assumptions on railway:

- In 2020, freight traffic volume will reach 35 million tons.
- In 2020, the average freight transport distance will decrease to 250 km.
- Energy consumption per turnover volume keeps at 45.5 (tce/ 1 million tons ·km) from 2009 to 2020.

Assumptions on highway:

- Freight traffic volume of highway equals to total freight traffic volume minus the sum of freight traffic volume of railway, water way and civil aviation. According to Shanghai's Transportation Development Plan (2006-2020), freight traffic volume will reach 1.3 billion tons in 2020. Thus freight traffic volume of highway will be 707 million tons.
- The average freight transport distance remains 23km from 2009 to 2020.
- Energy consumption per turnover volume remains 83.84 (tce/ 1 million tons ·km) from 2009 to 2020.

Assumptions on waterway:

- In 2020, freight traffic volume will reach 550 million tons.
- The average freight transport distance remains 3469 km from 2009 to 2020.
- Energy consumption per turnover volume keeps at 4.5 (tce/ 1 million tons ·km) from 2009 to 2020.

Assumptions on civil aviation:

- In 2020, freight traffic volume will reach 8 million tons.
- The average freight transport distance remains 1122 km from 2009 to 2020.
- Energy consumption per turnover volume keeps at 518 (tce/ 1 million tons ·km) from 2009 to 2020.

(2) Scenario Parameters

According to the above assumptions, energy consumption of freight transport by different modes is shown in the following table.

Table 3- 20 Energy Consumption of Shanghai's Freight Transport by Different Modes (Transformation Scenario)

Energy Consumption (10 000 ton SCE)	2000	2010	2015	2020
Railway	55.51	14.19	23.79	39.81
Highway	46.95	77.06	102.49	136.33
Waterway	289.48	613.48	725.81	858.95
Civil Aviation	62.16	189.48	296.92	464.96

3.5.1.2.2 Moderate Intervention Scenario

(1) Scenario Assumptions

Assumptions on railway:

- In 2020, freight traffic volume will reach 35 million tons.
- In 2020, the average freight transport distance will decrease to 250 km.
- Energy consumption per turnover volume will decrease from 45.5 (tce/ 1 million tons ·km) in 2008 to 42.5 (tce/ 1 million tons ·km) in 2020.

Assumptions on highway:

- Freight traffic volume of highway freight traffic volume of highway will be 707 million tons in 2020.
- The average freight transport distance remains 23km from 2009 to 2020.
- Energy consumption per turnover volume will decline from 83.84 (tce/ 1 million tons ·km) in 2008 to 77.50 (tce/ 1 million tons ·km) in 2020.

Assumptions on waterway:

- In 2020, freight traffic volume will reach 550 million tons.
- The average freight transport distance remains 3469 km from 2009 to 2020.
- Energy consumption per turnover volume will remain 4.5 (tce/ 1 million tons ·km) from 2008 to 2020.

Assumptions on civil aviation:

- In 2020, freight traffic volume will reach 8 million tons.
- The average freight transport distance remains 1122 km from 2009 to 2020.

- Energy consumption per turnover volume will decline from 518(tce/ 1 million tons ·km) in 2008 to 480 (tce/ 1 million tons ·km) in 2020.

(2) Scenario Parameters

According to the above assumptions, energy consumption of freight transport by different modes is shown in the following table.

Table 3- 21 Energy Consumption of Shanghai's Freight Transport by Different Modes (Moderate Intervention Scenario)

Energy Consumption (10 000 ton SCE)	2000	2010	2015	2020
Railway	55.51	14.03	22.86	37.19
Highway	46.95	76.05	97.88	126.02
Waterway	289.48	613.32	725.49	858.58
Civil Aviation	62.16	187.07	283.95	430.84

3.5.1.2.3 Strong Intervention Scenario

(1) Scenario Assumptions

Assumptions on railway:

- In 2020, freight traffic volume will reach 25 million tons.
- In 2020, the average freight transport distance will decrease to 250 km.
- Energy consumption per turnover volume will decrease from 45.5 (tce/ 1 million tons ·km) in 2008 to 42.5 (tce/ 1 million tons ·km) in 2020.

Assumptions on highway:

- Freight traffic volume of highway will be 707 million tons in 2020.
- The average freight transport distance remains 23km from 2009 to 2020.
- Energy consumption per turnover volume will decline from 83.84 (tce/ 1 million tons ·km) in 2008 to 74.50 (tce/ 1 million tons ·km) in 2020.

Assumptions on waterway:

- In 2020, freight traffic volume will reach 550 million tons.
- The average freight transport distance remains 3469 km from 2009 to 2020.
- Energy consumption per turnover volume will decrease from 4.5 (tce/ 1 million tons ·km) in 2008 to 4.35 (tce/ 1 million tons ·km) in2020.

Assumptions on civil aviation:

- In 2020, freight traffic volume will reach 8 million tons.
- The average freight transport distance remains 1122 km from 2009 to 2020.
- Energy consumption per turnover volume will decline from 518(tce/ 1 million tons ·km) in 2008 to 480 (tce/ 1 million tons ·km) in 2020.

(2) Scenario Parameters

According to the above assumptions, energy consumption of freight transport by different modes is shown in the following table.

Table 3- 22 Energy Consumption of Shanghai's Freight Transport by Different Modes (Strong Intervention Scenario)

Energy Consumption (10 000 ton SCE)	2000	2010	2015	2020
Railway	55.51	13.60	19.01	26.56
Highway	46.95	75.55	95.66	121.14
Waterway	289.48	610.06	711.74	829.96
Civil Aviation	62.16	187.07	283.95	430.85

3.5.2 Passenger Transport

3.5.2.1 Current Situation

3.5.2.1.1 Trend of Total Passenger Traffic

Many metropolises face the similar problems of transport congestion, air pollution and transport security. Meanwhile, when city passenger transport is during the period of economic boom, private car ownership and its utilization rate will be on the rise and become a main resource of carbon dioxide emission in the city transportation system.

Shanghai has the limitation policy of private car ownership (i.e. license plates auction), so the number of private cars won't increase by a large margin. However, the utilization rate of taxies is high, which will lead to a large amount of carbon dioxide emission in urban transportation system. Due to the construction of rail transit and the improvement of ground public transportation in Shanghai, the share of public traffic still keeps at a relatively large percentage. Furthermore, according to the Annual Report of Shanghai Transportation 2009, the percentage of non-motorization transportation[12] is 46.2% in 2008, which benefits the mitigation of carbon dioxide emission.

Total passenger traffic is relevant to the change of population, i.e. the more the population is, the larger the passenger traffic is. With the development of economy and the improvement of living standard, trip intensity per capita will increase. According to Shanghai's third transportation survey, trip intensity per capita is increasing from 1.80 times/person day in the 1990s to 2.1 times/ person day in 2004. In the future, trip intensity per capita will increase further.

However, carbon dioxide emission in passenger transport is not directly related with total passenger traffic, but relevant to the mileage of different transportation modes. Table 3-23 and 3-24 include current situation of car, taxi, rail transit, bus and civil aviation in Shanghai.

Table 3- 23 Current Situation of Shanghai's Passenger Transport (2000-2008)

Year	Car (10 000 vehicles)	Taxi		Rail Transit		Bus	
		Passenger Traffic (100 million person/time)	Mileage Covered (100 million km)	Passenger Traffic (100 million person/time)	Mileage Covered (100 million km)	Passenger Traffic (100 million person/time)	Mileage Covered (100 million km)
2000	-	7.52	46.48	1.36	0.03	26.49	9.32
2001	24.05	7.36	46.07	2.83	0.05	26.84	9.98
2002	29.37	8.82	51.37	3.57	0.06	27.75	10.43
2003	36.16	9.95	56.45	4.06	0.08	27.31	10.80
2004	44.60	10.92	57.90	4.80	0.10	28.38	11.41
2005	53.59	11.28	58.12	5.94	0.11	27.81	11.30
2006	62.81	11.78	61.05	6.56	0.15	27.40	11.28
2007	72.81	11.55	60.66	8.14	0.17	26.50	11.32
2008	82.96	12.32	63.18	11.28	0.25	26.60	11.90

Data Source: Shanghai Statistical Yearbook on Industry, Energy and Transport

[12] Non-motorization traffic includes bicycles and walking.

Table 3- 24 Current Situation of Shanghai's Civil Aviation for Passenger Transport (2000-2008)

Year	Passenger Throughput (10 000 person/time)	Turnover Volume (100 million person ·km)
2000	1784	176.101
2001	2084	201.30
2002	2472	237.80
2003	2482	252.88
2004	3612	476.70
2005	4160	535.48
2006	4618	600.28
2007	5217	731.79
2008	5130	715.09

Data Source: Shanghai Statistical Yearbook 2010

From the table 3-24, the share of public traffic can be calculated (see the figure 3-9). The percentage of buses of public traffic is on the decline from 74.89% in 2000 to 52.99% in 2008 and that of rail transit is on the rise from 3.85% in 2000 to 22.47% in 2008. The share of taxies is between 20% and 25%.

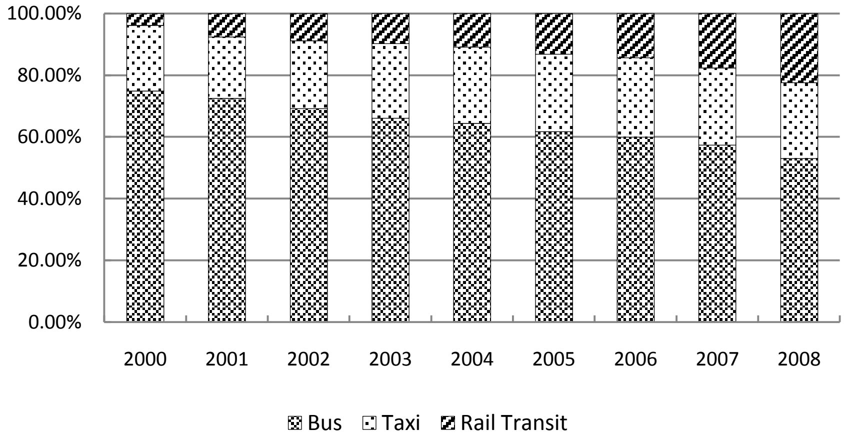

Figure 3- 9 Share of Public Traffic in Shanghai (2000-2008)

3.5.2.1.2 Development Trend of Different Means of Transportation

Car Ownership per 1000 persons is a vital parameter for the degree of motorization. And car ownership per 1000 persons is closely related with GDP per capita.

$$CO = \underset{(1.196)}{-15.542} + \underset{(0.252)}{9.473} GDPPC \qquad (4), \qquad \bar{R}^2 = 0.9951$$

where CO denotes car ownership per 1000 person and GDPPC denotes GDP per capita.

The coefficient of GDP per capita is statistically significant at 1% level and adjusted $\bar{R}^2$ is high. Then, we can use the regression (4) to predict car ownership per 1000 person in the future.

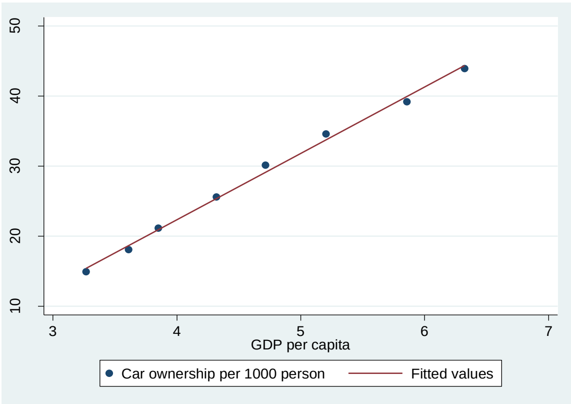

Figure 3- 10 Regression between Car Ownership per 1000 persons and GDP per Capita in Shanghai (2001-2008)

Through the linear regression (5) and (6), we can find there are significantly positive relation between mileage covered and passenger traffic of taxi and railway transit (see figure 3-18)

For taxi: $MC = \underset{(1.55)}{21.55} + \underset{(0.15)}{3.36}\,PT$ (5), $\bar{R}^2 = 0.9842$

For railway transit: $MC = \underset{(0.00660)}{-0.01217} + \underset{(0.00108)}{0.02286}\,PT$ (6), $\bar{R}^2 = 0.9823$

where MC stands for mileage covered and PT stands for passenger traffic. And we can use the above regressions to predict mileage covered of taxi and rail transit in the future.

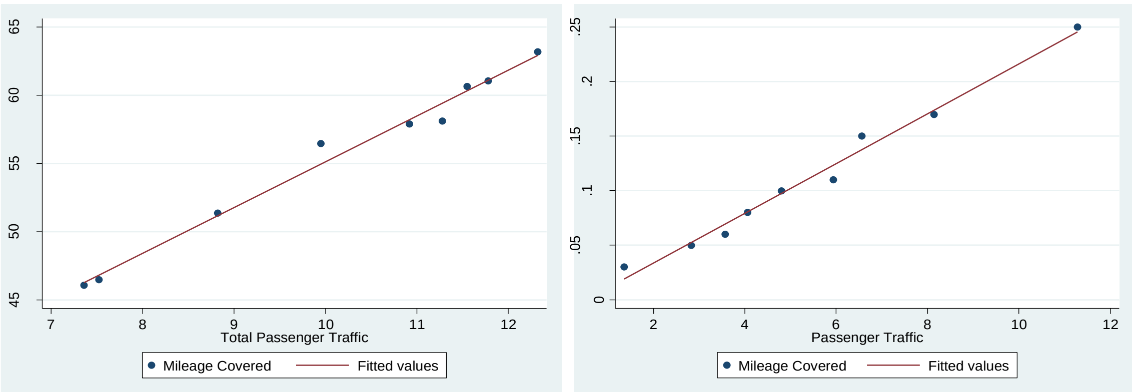

Figure 3- 11 Regression between Mileage Covered and Passenger Traffic of Taxi (Left) and Rail Transit (Right) in Shanghai (2000-2008)

Then, we use the same way to regress mileage covered and passenger traffic of bus and the regression result is as follows.

$$\underset{(12.001)}{MC = 1.598} + \underset{(0.441)}{0.340} PT \quad (7), \qquad \bar{R}^2 = -0.0532$$

From the regression (7), we can find that although mileage covered of bus is positively related with passenger traffic, the coefficient of passenger traffic is not statistically significant. Thus, this regression is not suitable to predict mileage covered of bus in the future and we have to find another parameter— passenger traffic per unit of mileage covered (person/ km). This parameter can reflect bus service efficiency and service level. From the figure 3-12, we can see that the parameter is on the decline, which means the service level of bus is enhanced gradually and the crowded condition in the bus has been improved. This also reflects that more people prefer to going out by private cars or rail transit.

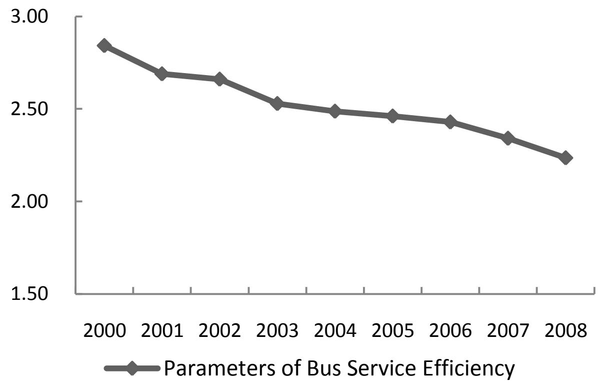

Figure 3- 12 Changing Trend of Bus Passenger Traffic per Mileage Covered in Shanghai (2000-2008)

Energy consumption of civil aviation is relevant to its turnover volume and the relationship is shown in the figure 3-13.

$$TV = 0.005 PT^{1.3895} \quad (8), \qquad R^2 = 0.9918$$

where TV is turnover volume and PT is passenger throughput.

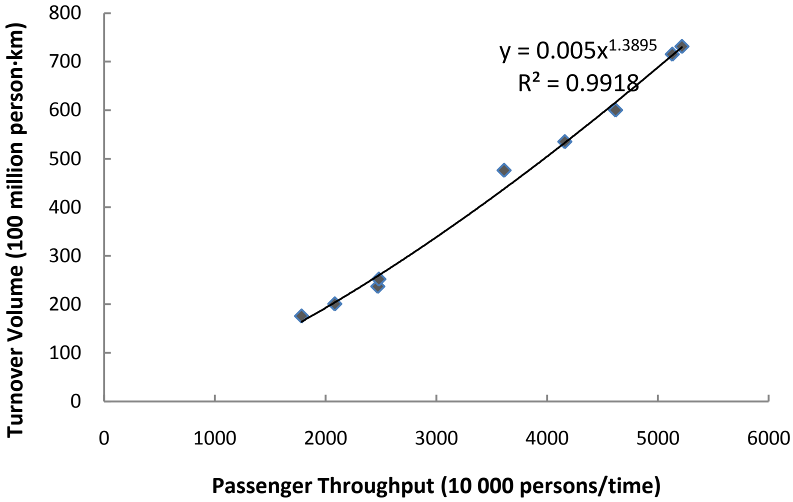

Figure 3- 13 Regression between Turnover Volume and Passenger Throughput of Civil Aviation in Shanghai (2000-2009)

In 2008, passenger throughput in Shanghai Pudong and Hongqiao airport has reached 51.30 million persons/time. According to the Strategic Plan of Shanghai Airport Hub, passenger throughout of civil aviation will be about 100 million persons/time.

Energy consumption by various means of transportation is different. According to the survey about several bus lines in the city center and suburban area of Shanghai, the average oil consumption of bus is 40L/100km, and that of taxi is 10 L/100km (Zhao et al., 2009) According to Li et al. (2008)'s analysis on operation cost of family cars, the average oil consumption of cars is 8.8L/100 km. In general, energy consumption of rail transit is calculated by electricity consumption. Based on the Annual Report of Shanghai Shentong Metro Corporation (2003), electricity consumption of rail transit is 263.8KWh/100 km. Energy consumption of civil aviation is 0.102 kgce/ person • km.

3.5.2.2 Scenario Analysis of Passenger Traffic

3.5.2.2.1 Transformation Scenario

(1) Scenario Assumptions

There are different methods for various means of transportation to calculate their energy consumption. The detailed methods and assumptions are as follows.

Firstly, for cars we can predict the car ownership per 1000 person from 2010 to 2020 through the regression (4), and get the number of cars. Then by the assumptions on average mileage per vehicle we can calculate total mileage covered of cars. Finally, according to assumptions on oil consumption of car, energy consumption can be calculated.

Assumptions on cars:

- Currently, average mileage per vehicle in Shanghai is 13575 km/vehicle •year (Li et al., 2008) and it will decrease to 12600 km/vehicle • year in 2020.
- Oil consumption of cars keeps at 8.8L/100 km.

Secondly, general assumptions on public transportation (including buses, rail transit and taxies) are as follows:

- The share of public transportation (including buses, rail transit and taxies) can be assumed based on the Plan of Shanghai's Public Transportation Development and the 'twelfth five-year plan'. Trip intensity per capita is increasing from 2.10 times/person day in 2004 to 2.48 times/ person day in 2010 and 2.65 times/person day in 2020.
- Share of public transportation is about 30%.

For buses, we can get total passenger traffic volume by the assumptions on the share of bus of public transportation. According to the parameter of service efficiency (i.e. passenger traffic per unit of mileage covered), the total mileage covered of buses can be calculated. Finally, energy consumption can be calculated by the assumptions on oil consumption of buses.

Assumptions on buses:

- The share of buses of public transportation will decrease from 52.99% in 2008 to 46% in 2020.
- From 2011 to 2020, passenger traffic per unit of mileage covered remains 2.23 person/ km.
- Oil consumption keeps at 40L/100 km.

For rail transit and taxies, we also can get total passenger traffic volume by the assumptions on the share of bus of public transportation. Then through the regression between mileage covered and passenger traffic (i.e. regression (5) and (6)), the total mileage covered of rail transit and taxies can be calculated. Finally, energy consumption can be calculated by the assumptions on oil consumption of taxi and electricity consumption of rail transit.

Assumptions on rail transit:

- The share of rail transit of public transportation will increase to 35% in 2020.
- Electricity consumption remains 263.9 KWh/ 100 km.

Assumptions on taxies:

- The share of taxies can be calculated by one hundred percent minus the sum of the share of buses and rail transit.
- Oil consumption remains 10L/100 km.

Thirdly, for civil aviation we can predict passenger turnover volume by the regression (8) and the Strategic Plan of Shanghai Airport Hub. Then energy consumption of civil aviation can be calculated by turnover volume per passenger.

Assumptions on civil aviation:

- Passenger throughout of civil aviation will increase from 51.30 million persons/time in 2008 to 100 million persons/time in 2020.
- Energy consumption keeps at 0.102 kgce/ person • km

(2) Results of Scenario Analysis

According to the above assumptions, energy consumption of different passenger traffic mode is illustrated in the table 3-25.

Table 3- 25 Energy Consumption of Shanghai's Passenger Traffic by Different Modes (Transformation Scenario)

Different Mode of Passenger Traffic		2000	2010	2015	2020
Cars	93# Gasoline (L)	2.41E+08	1.21E+09	1.81E+09	2.50E+09
Taxies	93# Gasoline (L)	4.65E+08	6.47E+08	6.58E+08	6.45E+08
	Energy Consumption of Gasoline (10 000 tons SCE)	75.32	198.54	262.99	334.95
Buses	0# Diesel Oil (L)	3.73E+08	4.95E+08	5.22E+08	5.55E+08
	Energy Consumption (10 000 tons SCE)	45.36	60.24	63.46	67.50
Rail Transit	Electricity Consumption (KWh)	7.92E+06	7.75E+07	1.04E+08	1.42E+08
	Energy Consumption (10 000 tons SCE)	0.25	2.44	3.28	4.46
Civil Aviation	Energy Consumption (10 000 tons SCE)	179.52	850.96	1252.40	1843.19

3.5.2.2.2 Moderate Intervention Scenario

The methods to calculate energy consumption for different mode of passenger transport are the same under all scenarios.

(1) Scenario Assumptions

Assumptions on cars:

- Currently, average mileage per vehicle in Shanghai is 13575 km/vehicle •year (Li et al., 2008) and it will decrease to 11800 km/vehicle • year in 2020.
- Oil consumption of cars will reduce from 8.8L/100 km in 2010 to 7.5L/100 km in 2020.

General assumptions on public transportation (including buses, rail transit and taxies) are as follows:

- Trip intensity per capita is increasing from 2.10 times/person·day in 2004 to 2.48 times/ person·day in 2010 and 2.65 times/person·day in 2020.
- Share of public transportation will increase from 30% in 2010 to 32% in 2020

Assumptions on buses:

- The share of buses of public transportation will decrease from 52.99% in 2008 to 44% in 2020.
- From 2011 to 2020, passenger traffic per unit of mileage covered remains 2.23 person/ km.
- Oil consumption will reduce from 40L/100 km in 2010 to 35L/100 km in 2020.

Assumptions on rail transit:

- The share of rail transit of public transportation will increase to 38% in 2020.
- Electricity consumption remains 263.9 KWh/ 100 km.

Assumptions on taxies:

- The share of taxies can be calculated by one hundred percent minus the sum of the share of buses and rail transit.
- Oil consumption will decrease from 10L/100 km in 2010 to 7.5L/100 km in 2020.

Assumptions on civil aviation:

- Passenger throughout of civil aviation will increase from 51.30 million persons/time in 2008 to 100 million persons/time in 2020.

- Energy consumption will reduce from 0.102 kgce/ person • km in 2010 to 0.090 kgce/ person • km.

(2) Results of Scenario Analysis

According to the above assumptions, energy consumption of different passenger traffic mode is illustrated in the table 3-26.

Table 3- 26 Energy Consumption of Shanghai's Passenger Traffic by Different Modes (Moderate Intervention Scenario)

Different Mode of Passenger Traffic		2000	2010	2015	2020
Cars	93# Gasoline (L)	2.41E+08	1.20E+09	1.61E+09	1.99E+09
Taxies	93# Gasoline (L)	4.65E+08	6.47E+08	6.17E+08	5.52E+08
	Energy Consumption of Gasoline (10 000 tons SCE)	75.32	197.23	237.11	271.32
Buses	0# Diesel Oil (L)	3.73E+08	4.92E+08	4.91E+08	4.95E+08
	Energy Consumption (10 000 tons SCE)	45.36	59.80	59.76	60.26
Rail Transit	Electricity Consumption (KWh)	7.92E+06	7.86E+07	1.13E+08	1.64E+08
	Energy Consumption (10 000 tons SCE)	0.25	2.47	3.56	5.16
Civil Aviation	Energy Consumption (10 000 tons SCE)	179.52	850.96	1208.87	1716.70

3.5.2.2.3 Strong Intervention Scenario

(1) Scenario Assumptions

Assumptions on cars:

- Currently, average mileage per vehicle in Shanghai is 13575 km/vehicle •year (Li et al., 2008) and it will decrease to 11200 km/vehicle • year in 2020.
- Oil consumption of cars will reduce from 8.8L/100 km in 2008 to 7.2L/100 km in 2020.

General assumptions on public transportation are the same as that under moderate intervention scenario.

Assumptions on buses:

- The share of buses of public transportation will decrease from 52.99% in 2008 to 38% in 2020.
- From 2011 to 2020, passenger traffic per unit of mileage covered remains 2.23 person/

km.

- Oil consumption will reduce from 40L/100 km in 2010 to 34L/100 km in 2020.

Assumptions on rail transit:

- The share of rail transit of public transportation will increase to 42% in 2020.
- Electricity consumption remains 263.9 KWh/ 100 km.

Assumptions on taxies:

- The share of taxies can be calculated by one hundred percent minus the sum of the share of buses and rail transit.
- Oil consumption will decrease from 10L/100 km in 2010 to 8.5L/100 km in 2020.

Assumptions on civil aviation:

- Passenger throughout of civil aviation will increase from 51.30 million persons/time in 2008 to 100 million persons/time in 2020.
- Energy consumption will reduce from 0.102 kgce/ person • km in 2010 to 0.095kgce/ person • km.

(2) Results of Scenario Analysis

According to the above assumptions, energy consumption of different passenger traffic mode is illustrated in the table 3-27.

Table 3- 27 Energy Consumption of Shanghai's Passenger Traffic by Different Modes (Strong Intervention Scenario)

Different Mode of Passenger Traffic		2000	2010	2015	2020
Cars	93# Gasoline (L)	2.41E+08	1.19E+09	1.53E+09	1.81E+09
Taxies	93# Gasoline (L)	4.65E+08	6.62E+08	6.16E+08	5.23E+08
	Energy Consumption of Gasoline (10 000 tons SCE)	75.32	197.32	228.46	249.38
Buses	0# Diesel Oil (L)	3.73E+08	4.80E+08	4.44E+08	4.16E+08
	Energy Consumption (10 000 tons SCE)	45.36	58.36	54.05	50.56
Rail Transit	Electricity Consumption (KWh)	7.92E+06	7.99E+07	1.20E+08	1.81E+08
	Energy Consumption (10 000 tons SCE)	0.25	2.52	3.77	5.71
Civil Aviation	Energy Consumption (10 000 tons SCE)	179.52	850.96	1176.98	1626.34

3.6 Energy Structure

Shanghai's energy consumption has experienced a rapid growth in the past ten years. In 2008, primary energy consumption has reached 10314.17 (10 000 tons SCE). The share of coal, oil, natural gas and electricity outside Shanghai[13] is 44.2%, 40.9%, 3.8% and 10.8% respectively. The development of low carbon society in Shanghai relies on the application of wind power and solar power, the rising percentage of natural gas and electricity outside Shanghai and the declining percentage of coal and oil.

3.6.1 Current Situation

3.6.1.1 Development of wind power and solar power

Wind power can be separated into offshore and onshore wind power. Shanghai is located in China's eastern coast and has East Asian Monsoon climate, which has the advantage of developing offshore wind power. In 2010, the first large offshore wind power plant (i.e. the Eastern Sea Bridge wind power program) has been established. Its total installed capacity is 102 MW and electricity generation on grid is about 267 GWh. Shanghai plans to increase total installed capacity of wind power to 0.5 GW in 2012 and to 1.520 GW in 2020.

The main utilization of solar energy is solar photovoltaic. In 2008, the on-grid electricity price of Qianwei Solar Power Program[14] is about 4 yuan/KWh (including taxes). Its installed capacity is 1046 KW and annual on-grid electricity generation is about 1.073 GWh. In 2009, New Energy and Renewable Energy Department of National Energy Administration stated that the electricity price of solar power is planned to be 1.09 yuan/KWh. Although the cost of solar power is decreasing, it is still much higher than that of thermal power. Thus solar photovoltaic is at its preliminary and experimental stage in Shanghai. According to the plan, Shanghai's installed capacity of solar power is only 150 MW in 2020.

3.6.1.2 Development of Nuclear Power and Hydropower

According to the Mediate and Long Term Plan of Nuclear Power (2007), China's electricity installed capacity of nuclear power will reach 40 GW in 2020, and its annual electricity generation will be between 260 and 280 TWh. However, in recent years the growth of nuclear power has exceeded what is expected in the Mediate and Long Term Plan of

[13] Electricity outside Shanghai mainly represents for hydropower, nuclear power and coal-fired power from other provinces of China.

[14] Qianwei Solar Power Program is located at Qianwei village of Chongming District in Shanghai.

Nuclear Power. Based on the predict by Ye Qizhen who is a famous expert of nuclear power in China, installed capacity will reach 70GW in 2020. In 2008, installed capacity of East China Power Grid[15] is 5.07 GW, which occupies 57.3% of China's total installed capacity of nuclear power. According to rough estimation, in 2020 installed capacity of nuclear power in eastern electric grid of China will be about 45.7 GW which accounts for 65.3% of total installed capacity of China's nuclear power.

Hydropower is an important renewable energy in China. In 2008, installed capacity of China's hydropower is 172.6 GW which accounts for 21.77% of total installed capacity, and annual electricity generation is 565.5 TWh which account for 16.39% of total electricity generation[16]. According the Mediate and Long Term Plan for Renewable Energy (2007), China's installed capacity of hydropower will reach 300 GW. By rough estimation, the share of installed capacity in eastern electric grid of China is about 13%.

3.6.1.3 Development of Natural Gas

In 2008, Shanghai has two sources of natural gas: one is the first-line of West-East Natural Gas Transmission Project[17] and its quantity of natural gas supply is 2.37 billion m^3; the other is Pinghu oil and gas field in east China sea and its quantity of natural gas supply is about 0.6 billion m^3 in 2008. The total quantity of natural gas is about 3 billion m^3 and about 12.2% of that (i.e. 0.365 billion m^3) is used for electricity generation. However, the above two natural gas supplies can't fulfill the demand, so Shanghai needs new sources of natural gas. In the future, Malaysia LNG (Liquefied Natural Gas) will be the main sources of natural gas in Shanghai. In 2009, Malaysia started to transmit liquefied natural gas to Shanghai and its annual quantity is 1.1 million tons and will increase gradually. After 2012, annual supply of natural gas will be 3 million tons (about 4 billion m^3). The fourth source of natural gas is Sichuan-East Natural Gas Transmission Project[18] and its annual quantity of natural gas supply is about 1.9 billion m^3 in 2010. The fifth source is the second-line of

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[15] East China Power Grid includes four provinces and one city—Jiangsu Province, Zhejiang Province, Anhui Province, Fujian Province and Shanghai.

[16] According to China Electricity Yearbook 2009, total installed capacity is 792.72 GW and total annual electricity generation is 3451 TWh.

[17] West-East Natural Gas Transmission Project is to transmit natural gas from western area to east China.

[18] Sichuan-East Natural Gas Transmission Project is to transmit natural gas for Sichuan Province to east China.

West-East natural Gas Transmission Project and its annual supply is about 2 billion m^3. In 2011, Shanghai's natural gas will exceed 10 billion m^3 through the five sources of natural gas supply.

3.6.2 Scenario Analysis of Energy Structure

3.6.2.1 Transformation Scenario

(1) Scenario Assumptions

- In 2020, installed capacity of wind power will be about 1.52 GW. Wind power generation is estimated by the ratio of electricity generation and installed capacity in the Eastern Sea Bridge wind power program.
- In 2020, installed capacity of solar power will reach 0.15 GW. Solar power generation is estimated by the ratio of electricity generation and installed capacity in Qianwei Solar Power Program.
- In 2020, China's installed capacity of nuclear power will be about 70 GW and the share of installed capacity in eastern electric grid is about 65.3%. Nuclear power generation can be calculated by the ratio of electricity generation and installed capacity in the Mediate and Long Term Plan of Nuclear Power (2007). According to the proportion of electricity generation in Shanghai[19], nuclear power generation can be estimated. Assume the proportion will increase from 6% in 2010 to 11% to 2020.
- In 2020, China's installed capacity of hydropower will reach 300 GW and the share of installed capacity in eastern electric grid is about 13%. Hydropower generation can be calculated by the ratio of electricity generation and installed capacity in 2008. Shanghai's hydro power generation can be estimated by the proportion of electricity generation in Shanghai. Assume the proportion will increase from 6% in 2010 to 11% to 2020.
- Oil and coal consumption of thermal power generation will keep at the level of 2008.
- In 2020, Shanghai's natural gas will reach 18 billion m^3, 35% of which will be used for electricity generation.
- Due to the rapid growth of oil consumption in transportation sector, oil consumption will

[19] Based on China Electricity Yearbook (2009), electricity generation of eastern electric grid is 719.4 TWh and that of Shanghai is 79.5 TWh. So the proportion of Shanghai's hydro power generation is about 11%.

be on the rise and its share of total energy consumption will increase from 41.37% in 2008 to 45% in 2020.

- After 2008, coal consumption will be on the decline and it can be calculated by total final energy consumption[20] minus oil, natural gas and non fossil fuel energy.

(2) Results of Scenario Analysis

Final energy consumption structure is illustrated in the following table.

Table 3- 28 Final Energy Consumption Structure (Transformation Scenario)

Year		2000	2010	2015	2020
Coal		66.37%	46.46%	37.46%	29.42%
Oil		33.07%	41.95%	43.44%	45.00%
Natural Gas		0.56%	9.01%	13.30%	14.99%
Non Fossil Fuel Energy	Nuclear Power	0.00%	0.98%	3.52%	6.94%
	Hydropower	0.00%	1.54%	2.07%	2.83%
	Wind Power	0.00%	0.06%	0.22%	0.78%
	Solar Power	0.00%	0.00%	0.01%	0.03%

3.6.2.2 Moderate Intervention Scenario

(1) Scenario Assumptions

Most of the assumptions are similar to that under transformation scenario. The main difference is that coal will be substituted further by the increasing of renewable energy and natural gas. The relative assumptions are as follows:

- In 2020, installed capacity of solar power will reach 0.20 GW.
- In 2020, Shanghai's natural gas will reach 19 billion m^3.

(2) Results of Scenario Analysis

Final energy consumption structure is shown in the following table.

[20] Total final energy consumption is estimated by the sum of energy consumption in primary industry, secondary industry, residential and public buildings, freight and passenger transportations.

Table 3- 29 Final Energy Consumption Structure (Moderate Intervention Scenario)

Year		2000	2010	2015	2020
Coal		66.37%	49.95%	41.47%	25.63%
Oil		33.07%	41.95%	43.44%	45.00%
Natural Gas		0.56%	5.51%	9.89%	17.59%
Non Fossil Fuel Energy	Nuclear Power	0.00%	0.98%	3.76%	7.71%
	Hydropower	0.00%	1.54%	2.21%	3.15%
	Wind Power	0.00%	0.06%	0.23%	0.87%
	Solar Power	0.00%	0.00%	0.01%	0.04%

3.6.2.3 Strong Intervention Scenario

The assumptions are the same as that under moderate intervention scenario. The results are illustrated in the table 3-30.

Table 3- 30 Final Energy Consumption Structure (Strong Intervention Scenario)

Year		2000	2010	2015	2020
Coal		66.37%	49.92%	39.49%	21.52%
Oil		33.07%	41.95%	43.44%	45.00%
Natural Gas		0.56%	5.53%	10.49%	20.05%
Non Fossil Fuel Energy	Nuclear Power	0.00%	0.99%	3.98%	8.79%
	Hydropower	0.00%	1.55%	2.34%	3.59%
	Wind Power	0.00%	0.06%	0.24%	0.99%
	Solar Power	0.00%	0.00%	0.01%	0.05%

4、Final Energy Consumption and Carbon Dioxide Emission in Shanghai

4.1 Final Energy Consumption

In Chapter 3, energy consumption in primary and secondary industry, buildings and transportation has been assessed by scenario analysis. Then we will aggregate them and analyze the total final energy consumption, final energy consumption per capita and energy intensity (i.e. final energy consumption per unit of GDP), respectively.

4.4.1 Total Final Energy Consumption

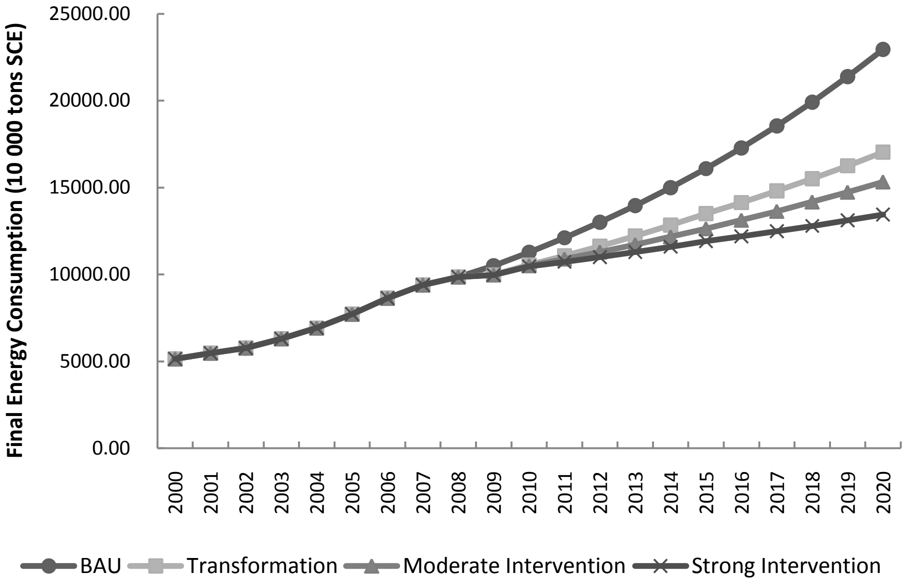

Figure 4- 1 Total Final Energy Consumption under Different Scenarios

With the rising of population and economic growth in Shanghai, the need for total final energy consumption will be on the rise. Under BAU scenario, final energy consumption grows at a high speed and it will reach 22955 (10 000 tons SCE) in 2020 which is three times larger than the level of 2005. Under transformation and moderate intervention scenario, the growth pace of final energy consumption is slower than that under BAU scenario, but it is also showing the continuous increasing trend. In 2020, final energy consumption will reach 17038 (10 000 tons SCE) under transformation scenario, while it will be 15327 (10 000 tons SCE) under moderate intervention scenario. Under strong intervention scenario, although final energy consumption increases steadily from 2010 to 2020, it is expected to reach the peak during 2020 and 2030, and then it will decrease in the future.

4.4.2 Final Energy Consumption Per Capita

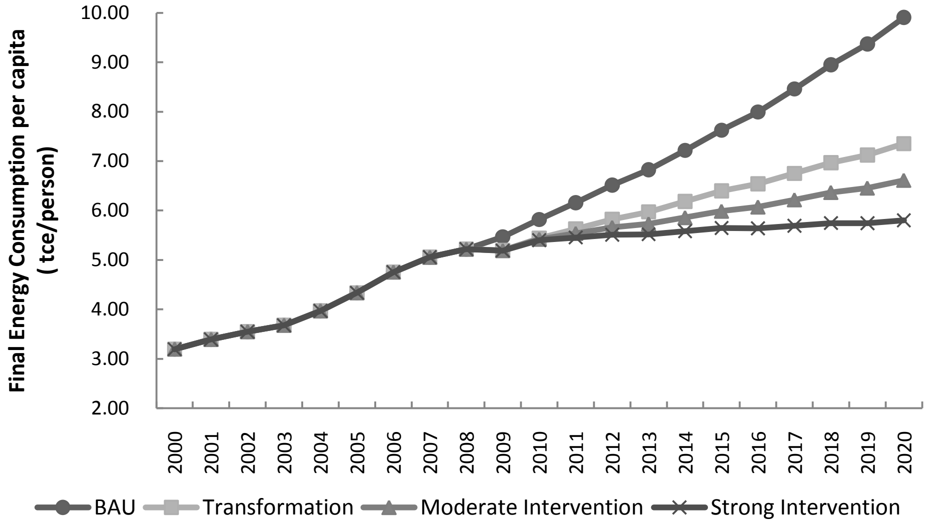

Figure 4- 2 Final Energy Consumption per Capita under Different Scenarios

Under BAU scenario, the growth of final energy consumption per capita keeps at a high speed, which is similar to the growth of total final energy consumption. It will reach 9.91 tce/person in 2020, which is 2.3 times larger than the level of 2005. Under transformation and moderate intervention scenario, final energy consumption per capita will increase gradually, but the growth speed is much slower than that under BAU scenario. In 2020, final energy consumption per capita will reach 7.35 tce/person under transformation scenario, while it will reach 6.61 tce/person under moderate intervention scenario. Under strong intervention scenario, after 2015 energy consumption per capita shows relatively steady trend and is around 5.7 tce/person.

4.4.3 Energy Intensity

Energy intensity in each scenario is showing the declining trend, and the difference is the declining degree (see table 4-1).

Table 4- 1 Final Energy Consumption per unit of GDP (2005=1)

Scenarios	2005	2010	2015	2020
BAU	1.00	0.87	0.81	0.75
Transformation	1.00	0.81	0.72	0.65
Moderate Intervention	1.00	0.81	0.67	0.59
Strong Intervention	1.00	0.81	0.65	0.55

4.4.4 Final Energy Consumption by Sectors

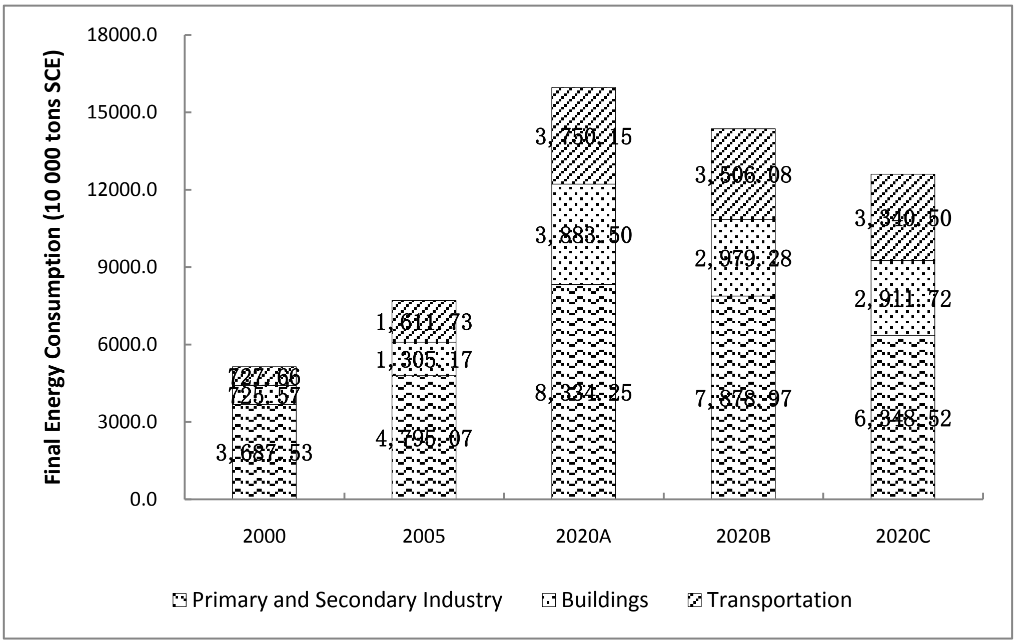

Figure 4- 3 Final Energy Consumption by Sectors under Different Scenarios

Figure 4-3 is about final energy consumption in primary and secondary industry, buildings and transportation sector. The share of primary and secondary industry will be on the decline in the future, while energy consumption in buildings and transportation sector will be on a rapid growth. Under different scenarios, final energy consumption by sector will show different changes.

For primary and secondary industry, under transformation scenario (i.e. 2020A in the figure 4-3) final energy consumption will increase from 4795 (10 000 tons SCE) in 2005 to 8334 (10 000 tons) in 2020, and its share of total final energy consumption will decrease from 71.73% in 2005 to 52.19% in 2020. Under moderate intervention scenario (i.e. 2020B in the figure 4-3), final energy consumption will increase to 7879 (10 000 tons SCE) in 2020, and its share will increase to 54.85%. Under strong intervention scenario (i.e. 2020C in the figure 4-3), final energy consumption will increase to 6349 (10 000 tons SCE) which is 1985 (10 000 tons SCE) less than the level under transformation scenario.

With the rising of population and the improvement of life standard, energy consumption in building sector will be on the rise in the future. Under transformation scenario final energy consumption will increase from 1305 (10 000 tons SCE) in 2005 to 3884 (10 000 tons SCE) and its share of total final energy consumption will rise from 16.92% to 24.32%. Under moderate scenario, final energy consumption is decreasing by a large margin. Compared to the level under transformation scenario, final energy consumption declines from 3884 (10 000 tons SCE) to 2979 (10 000 tons SCE). Under strong intervention scenario, final energy consumption will decline slightly from 2979 (10 000 tons SCE) to 2911 (10 000 tons SCE).

For transportation sector, under transformation scenario its final energy consumption will increase from 1612 (10 000 tons SCE) in 2005 to 3750 (10 000 tons SCE) in 2020, and its share of total final energy consumption will increase from 20.90% to 23.49%. Compared to transformation scenario, final energy consumption is 244 (10 000 tons SCE) less under moderate intervention scenario and 410 (10 000 tons SCE) less under strong intervention scenario.

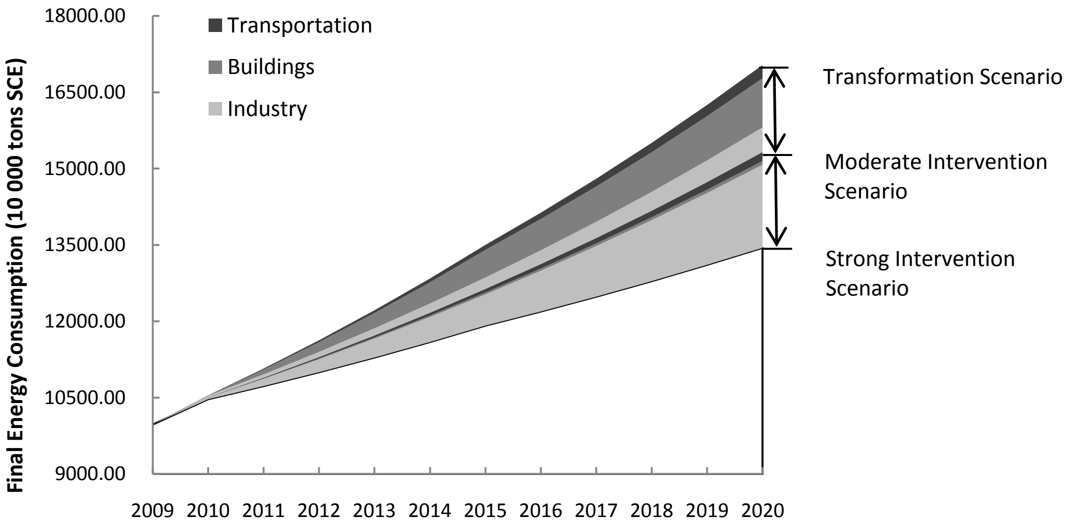

Figure 4- 4 Contributions of Different Sectors to Reducing Energy Consumption

From the figure 4-4, we can find that under moderate intervention scenario, the largest contributor to reducing final energy consumption is the building sector, the second one is primary and secondary industry and the smallest is transportation sector. However, under strong intervention scenario, the largest contributor to reducing final energy consumption is industrial sector. The main reason that demand control measures is taken strongly, industrial structure is adjusted, some heavy industries are phased out and economic growth is slowed down.

To make a conclusion, industrial sector has the largest potential to reduce final energy consumption and buildings sector has the second largest potential. For transportation sector, it is hard to control the energy demand, so its mitigation of final energy consumption is the smallest both under moderate and strong intervention scenarios.

4.2 Carbon Dioxide Emission

The emission level of carbon dioxide is estimated based on final energy consumption and energy structure. Coal, oil and natural gas are related to carbon dioxide emission. The carbon dioxide coefficient is shown in the table 4-2, and the third one is chosen to calculate carbon dioxide emission.

Table 4- 2 Carbon Dioxide Coefficient (kgc/kgce)

	Coal	Oil	Natural
U.S. Energy Information Administration (EIA)	0.702	0.478	0.389
Japan Institute of Energy	0.756	0.586	0.449
China Energy Research Institute	0.7476	0.5825	0.4435

4.2.1 Total Carbon Dioxide Emission

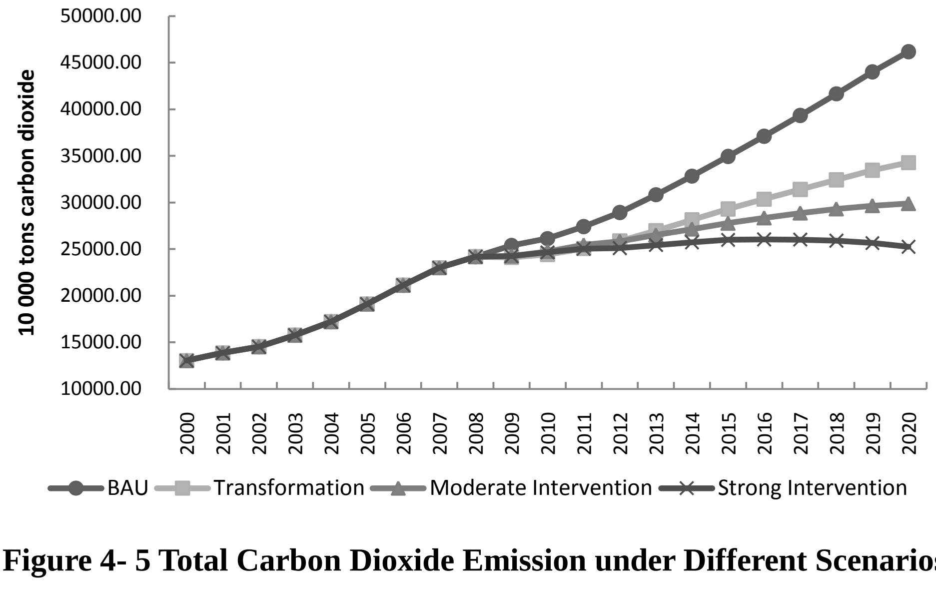

Figure 4- 5 Total Carbon Dioxide Emission under Different Scenarios

Under BAU scenario, total carbon dioxide emission is increasing rapidly. In 2020, the emission level will reach 46172 (10 000 tons CO_2), which is 2.4 times larger than the level of

2005.

Under transformation scenario, total carbon dioxide emission is also on the rise, but the growth speed is slower than that under BAU scenario. In 2020, the emission level will reach 34270 (10 000 tons CO_2).

Under moderate intervention scenario, after 2008 total carbon dioxide emission increases by a small margin and it will reach 29883 (10 000 tons CO_2) in 2020. The increasing trend is expected to be steady after 2020.

Under strong intervention scenario, the emission level will reach to the top in 2016, namely 26041 (10 000 tons CO_2). Afterwards, total carbon dioxide emission will decline gradually.

4.2.2 Carbon Dioxide Emission per Capita

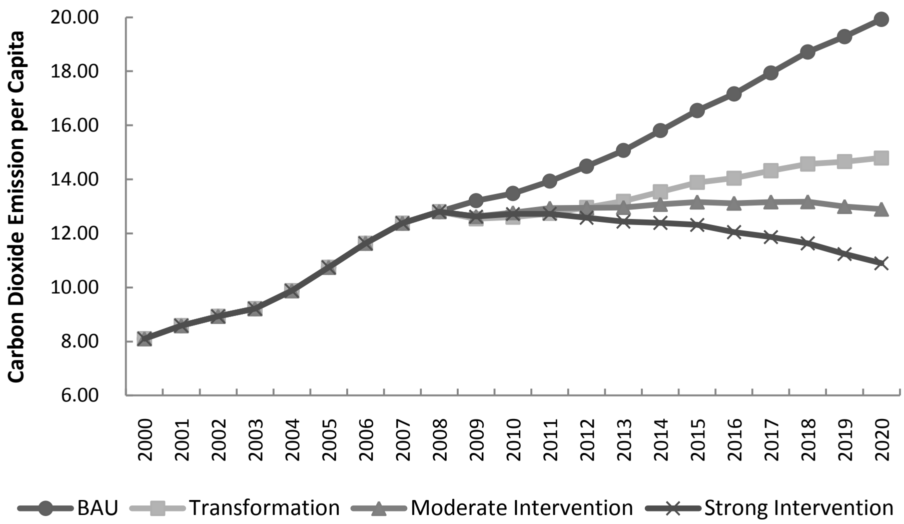

Figure 4- 6 Carbon Dioxide Emission per Capita under Different Scenarios

Under BAU scenario, carbon dioxide emission per capita will be on a rapid growth from 2009 to 2020. In 2020, it will reach 19.93 $tCO_2 / person$.

Under transformation scenario, carbon dioxide emission per capita will be on a slow growth from 2009 to 2020. After 2020, it is expected to reach the peak and then it will decline gradually.

Under moderate intervention scenario, carbon dioxide emission per capita will be around 13 $tCO_2 / person$ from 2012 to 2020 and after 2018 it is showing the declining trend.

Under strong intervention scenario, carbon dioxide emission per capita is around 12.7 $tCO_2 / person$ during 2008 and 2011. After 2011, it is declining gradually and it will be 10.89 $tCO_2 / person$ in 2020.

4.2.3 Carbon Dioxide Intensity

Under BAU scenario, carbon dioxide emission per unit of GDP will decrease by 39% compared to the level of 2005, which doesn't achieve the target. However, under the other three scenarios, carbon dioxide emission per unit of GDP will decrease by 47%, 54% and 58% respectively, which fulfill the goal (see the table 4-3).

Table 4- 3 Carbon Dioxide Emission per unit of GDP (2005=1)

Scenarios	2005	2010	2015	2020
BAU	1.00	0.81	0.71	0.61
Transformation	1.00	0.76	0.63	0.53
Moderate Intervention	1.00	0.77	0.60	0.46
Strong Intervention	1.00	0.77	0.58	0.42

One thing needs to be emphasized that Shanghai is in the transformation process of post-industrialization. For other cities in China, it is difficult to decrease carbon dioxide emission per unit of GDP by 40%-45% compared to the level of 2005 during the process of industrialization.

5、Countermeasures for Low Carbon Society in Shanghai

From the scenario analysis of chapter 3, the related measures can be taken to mitigate the emission level of carbon dioxide in Shanghai, such as enhancing energy efficiency, optimizing energy structure, adjusting industrial structure, planning the urban space, setting efficient and fast transportation system, developing energy-saving technologies. The detailed countermeasures are summarized as the following four aspects—industry, transportation, buildings and energy structure.

5.1 Industry

Enhancing industrial energy efficiency plays a vital role on the mitigation of carbon dioxide emission. The related measures can be taken as follows: the first is to reconstruct low energy efficiency industries and products for energy saving; the second is to eliminate outdated industrial capacity; the last one is that under the situation of non-increasing energy consumption, firms are encouraged to improve products' structure and quality, strengthen independent research and development capacity, develop new products, create their own brands and more economic value added. In the long run, the third one is the main measure to reduce industrial carbon dioxide emission.

Besides, adjustment of industrial structure is also very important, which means that heavy industry will decrease gradually and tertiary industry will increase. Thus, Shanghai's future developing direction is to develop modern services with low energy consumption, low emission level of carbon dioxide and high value added.

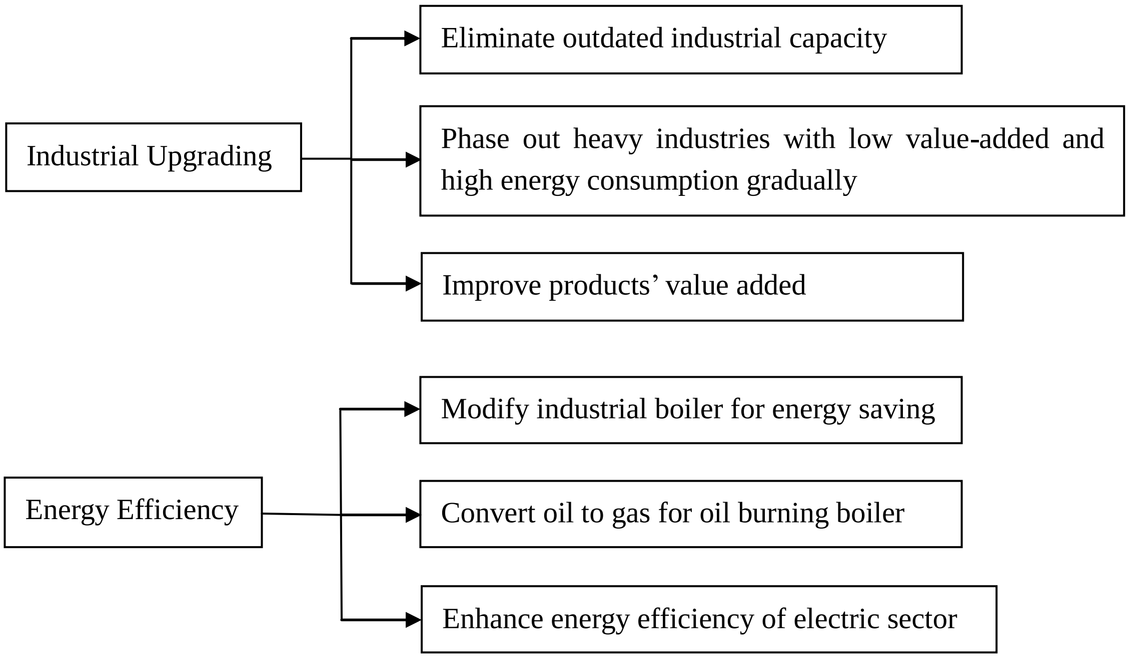

Figure 5- 1 Measures in Industrial Sector

5.2 Transportation

There are several ways to optimize urban traffic system:

- Make a proper design of bicycle paths and pavement and encourage more people to go out by bike or on foot.
- Develop urban public transportation, especially rail transit.
- Control the use of cars in city centre by license plate, charging expensive parking fee and congestion fee.

Another way to manage urban transport is to set up information-based traffic system. Besides, it is also important to increase the investment on R&D and the share of clean energy.

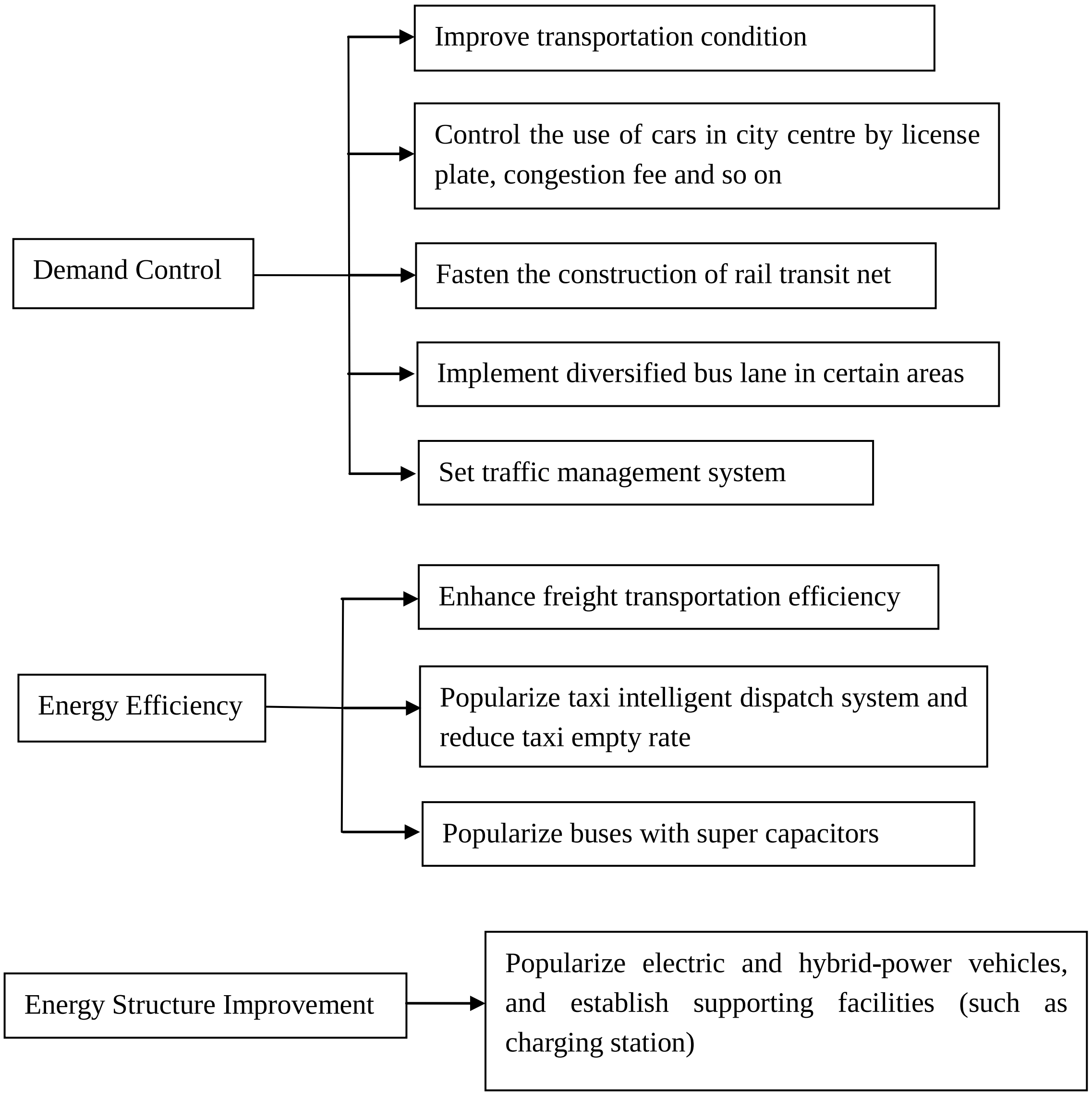

Figure 5- 2 Measures in Transportation Sector

5.3 Buildings

From the perspective of building demand, certain measures should be taken to control extravagant buildings.

For the construction, there are several aspects to control energy consumption:

- Raise energy-saving standards of buildings.
- Popularize energy-saving technology, such as heat insulation materials, water source or ground source heat pump system, solar water heater and solar photovoltaic system.
- Modify the existing buildings with high energy consumption.

➢ Extend buildings' service life and reduce large-scale reconstruction and demolishment.

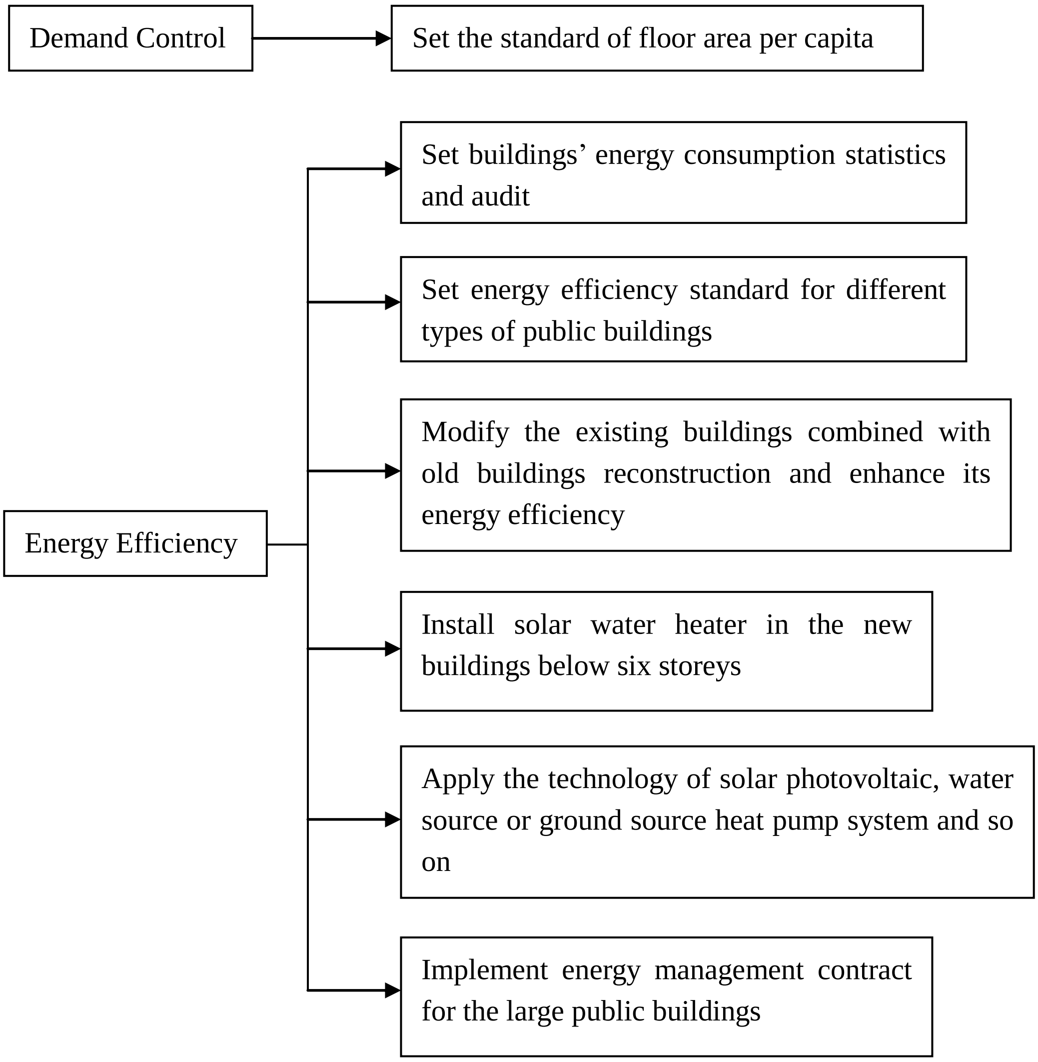

Figure 5- 3 Measure in Buildings Sector

5.4 Energy Structure

The improvement of energy structure mainly focuses on the following aspects:

First, increase the share of electricity outside Shanghai. With the rising of nuclear power and hydropower, increasing the share of electricity outside Shanghai not only reduce the demand of local coal but also reduce the emission level of carbon dioxide.

Second, upgrade the equipment of coal-fired power. With the development of technology, older coal-fired power equipment will be substituted and energy efficiency will be enhanced.

Third, increase the share of natural gas properly. If the sources of natural gas supply are steady, electricity generation by natural gas will be on the rise.

Fourth, develop renewable energy. The key of developing renewable energy is technology innovation.

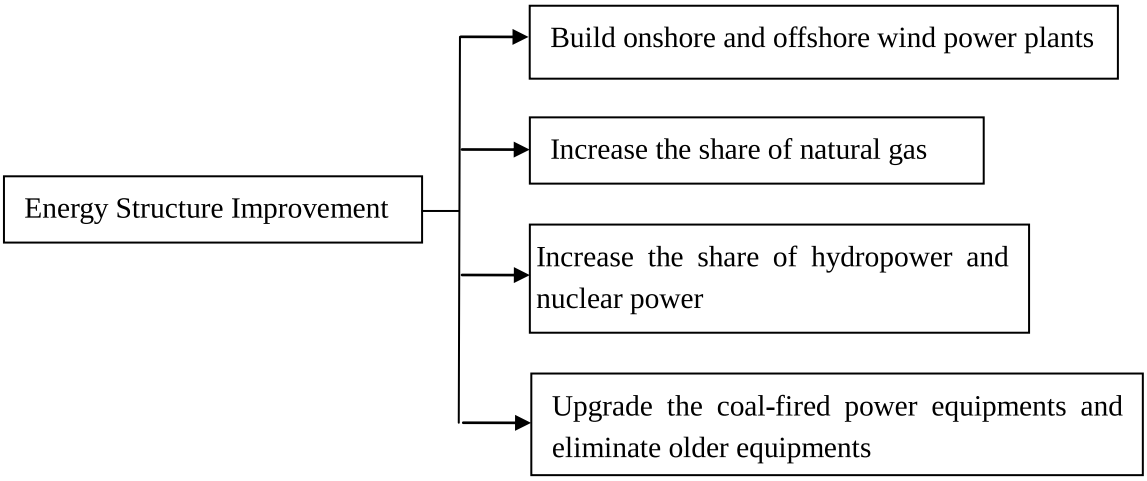

Figure 5- 4 Energy Structure Improvement Measures

6、Conclusion and Discussion

Nowadays, scenario analysis is widely used in social science. It is not only utilized by researchers to analyze the future possible images, but also utilized for policy-making or planning and for bridging the gap between science and policy. Climate change is a global issue and is affected by the total carbon dioxide emission of the world. Thus there are lots of studies focusing on national level carbon dioxide emission. However, it is also important to analyze the driving forces which influence the local-scale (or city) emission level in order to take effective measures. Furthermore, scenario analysis can present alternative images of future emission and it is useful for policy-makers to set policies and implement concrete countermeasures.

This thesis has developed the framework for scenario analysis of carbon dioxide emission at local level in China. Compared to the national level, the local level has some difficulties in obtaining data. Even though, it is possible to estimate the emission level of carbon dioxide in the future. And this framework is applied to Shanghai in 2020 and its target is to reduce carbon dioxide emission per unit of GDP by 40%-45% compared to the level of 2005.

This thesis elucidates the following points:

(1) This thesis has assessed energy demand (i.e. final energy consumption) by different sectors—industrial sector, buildings and transportation sector. Industrial sector has the largest contribution to total reduction amount, buildings sector is the second contributor and transportation sector has the smallest contribution.

(2) On the assumptions under BAU scenario, total carbon dioxide emission will reach 46172 (10 000 tons CO_2), carbon dioxide per capita will reach 19.93 $tCO_2 / person$ in 2020. However, carbon dioxide per unit of GDP will decrease by 39% compared to the level of 2005, which doesn't achieve the target.

(3) On the assumptions under transformation and moderate intervention scenarios, total carbon dioxide emission will increase from 2010 to 2020, while carbon dioxide per capita will be on the slow rise and become steady around 2020. What's more, carbon dioxide per unit of GDP will decline by 47% and 54% respectively, which fulfill the goal.

(4) On the assumptions under strong intervention scenario, total carbon dioxide emission will

reach 26041 (10 000 tons CO_2) in 2016 and then it will decline gradually. Carbon dioxide per capita is around 12.7 $tCO_2 / person$ from 2008 to 2011. After 2011, it will be on the decline. Carbon dioxide per unit of GDP will decline by 58%, which achieve the target.

(5) To bring about such large reduction under transformation, moderate and strong intervention scenarios, only energy demand control measures are not sufficient. Thus, energy demand control, energy efficiency improvement and energy structure measures should be taken simultaneously. The main countermeasures can be taken to mitigate the emission level of carbon dioxide in Shanghai, such as enhancing energy efficiency, optimizing energy structure, adjusting industrial structure, setting efficient and fast transportation system, developing energy-saving technologies.

The assess of carbon dioxide emission in Shanghai is mainly based on the assumptions of population increase, economic development, activity level and energy efficiency in different sectors and the changing trend of energy structure. These assumptions are based on the trend of each variable and other developed countries' experience. Maybe some assumptions seem to be subjective and judging the accuracy of assumptions is difficult, but they are reasonable to some extent. However, due to the limitation of data, there are also lots of uncertainties that influence the judgment. If there are more data that can be available in the future, the research can try to use different methods such as Extended Snapshot tool in Kei Gomi et al.(2010)'s study and macroeconomic tool in Koji Shimada et al. (2007)'s study. Besides, this thesis focuses on energy consumption as the major sources of carbon dioxide emission. However, there are other sources, such as the land use change, that emit carbon dioxide. Last but not least, it is not sufficient to analyze carbon dioxide emission scenarios only from the perspective of energy demand. For the further research, it is important to combine energy demand, energy supply and carbon sequestration together to assess the emission level of carbon dioxide.

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Appendix I Shanghai's Carbon Dioxide Emission (2000-2008)

According to Shanghai's energy balance table and the IPCC guideline, carbon dioxide emission is assessed from 2000 to 2008 by the following equations:

$$E = \sum_i A_i \times EF_i \qquad (1)$$

$$EF_i = NCV_i \times C_i \times O_i \times 44 \div 12 \qquad (2)$$

where A_i is the amount of consumption fuel i, EF_i is emission factor, NCV_i is net calorific value of fuel i (TJ/Gg), C_i is carbon content (kg/GJ) and O_i is carbon oxidation rate of fuel i. The value of each variable is shown in the table I-1 and I-2.

Table I- 1 Primary Energy Consumption in Shanghai (2000-2008) (Quantity in Kind)

Type/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008
Raw Coal (10 000 tons)	3297.96	3475.98	3548.85	3745.37	4007.80	4128.78	4033.75	4053.08	4297.71
Washed Clean Coal (10 000 tons)	1219.57	1126.43	1130.66	1205.53	1127.80	1159.79	1107.23	1201.31	1181.69
Coke (10 000 tons)	-54.24	-42.56	-82.45	-119.18	-181.52	-140.46	-92.78	-33.36	3.65
Coke-oven Gas (100 million cu. m)	-0.80	-0.96	0.00	0.00	0.00	0.00	0.00	0.14	0.00
Other Gas (100 million cu. m)	60.88	73.53	66.82	75.35	78.38	92.00	85.00	98.92	98.42
Crude Oil (10 000 tons)	1310.39	1356.29	1424.91	1737.51	1844.62	1967.00	1830.28	1719.57	1961.66
Gasoline (10 000 tons)	-131.38	-102.97	-107.85	-124.80	-69.09	-21.00	19.77	87.88	106.17
Kerosene (10 000 tons)	7.90	6.64	38.04	-1.42	31.20	44.07	149.70	174.51	189.65
Diesel Oil (10 000 tons)	-225.49	-214.41	-215.40	-320.03	-290.30	-388.44	-268.22	-194.47	-305.37
Fuel Oil (10 000 tons)	353.75	380.95	404.90	526.61	544.08	646.35	692.39	735.39	750.57
Liquefied Petroleum Gas (10 000 tons)	11.62	25.07	23.97	26.47	7.58	15.06	27.04	42.58	37.96
Refinery Gas (10 000 tons)	-2.47	-0.22	-1.90	0.02	-0.11	-1.90	-0.09	0.22	0.00
Natural Gas (100 million cu. m)	2.54	3.30	4.33	4.97	10.70	18.74	25.24	27.77	30.00
Other Petroleum Products (10 000 tons)	-67.06	-103.35	-16.97	-88.54	35.70	-60.73	243.90	301.24	179.90
Electricity (100 million KWh)	1.59	16.51	29.72	51.97	110.72	181.27	264.15	339.03	353.00

Data Source: China Energy Statistical Yearbook, Shanghai Statistical Yearbook on Industry, Energy and Transport

Table I- 2 Emission Factor

Fuel Type		(1) Net Calorific Value (TJ/Gg)	(2) Carbon Content (kgc/GJ)	(3) Carbon Oxidation Rate	Emission Factor (tCO_2/ton) (1)×(2)×(3) ×44÷12÷1000
Raw Coal and Washed Clean Coal	Anthracite	26.7	26.8	1	2.62
	Coking Coal	28.2	25.8	1	2.67
	Other Bituminous Coal	25.8	25.8	1	2.44
	Sub-Bituminous Coal	18.9	26.2	1	1.82
	Lignite	11.9	27.6	1	1.20
Coke		28.2	29.2	1	3.02
Coke Oven Gas		38.7	12.1	1	1.72
Other Gases	Gas Works Gas	38.7	12.1	1	1.72
	Blast Furnace Gas	2.5	70.8	1	0.64
	Oxygen Steel Furnace Gas	7.1	49.6	1	1.28
Crude Oil		42.3	20.0	1	3.10
Gasoline		44.3	19.0	1	3.08
Kerosene		43.8	19.6	1	3.15
Gas/Diesel Oil		43.0	20.2	1	3.18
Fuel Oil		40.4	21.1	1	3.13
Liquefied Petroleum Gases		47.3	17.2	1	2.98
Refinery Gas		49.5	15.7	1	2.85
Other Petroleum Products		40.2	20.0	1	2.95
Natural Gas		48.0	15.3	1	2.69

Data Source: IPCC Guideline 2006

In the table I-1, the unit of coke-oven gas, other gas and natural gas is 100 million cube meters, so we need to convert them into 10 000 tons. The density of coke-oven gas is 0.545 kg/m^3[21], that of other gas is 1.25 kg/m^3[22] and that of natural gas is 0.80 kg/m^3[23].

[21] Under standard temperature and pressure, the density of coke oven gas is 0.0.34 lbm/ft^3 and the conversion factor is that 1 lbm/ft^3=16.018 kg/m^3.

[22] Under standard temperature and pressure, the density of blast furnace gas is 1.250 kg/m^3. And gas works gas is mainly composed of carbon monoxide. The density of carbon monoxide is 1.250 kg/m^3. Thus the density of other gas is chosen as 1.250 kg/m^3.

In the table I-2, the emission factors of raw coal and washed clean coal are the average of anthracite, coke coal, other bituminous coal, sub-bituminous coal and lignite. The emission factor of other gases is the average of gas works gas, blast furnace gas and oxygen steel furnace gas. The emission factor of electricity is 0.846t CO_2/MWh[24]. According to the equation (1) and (2), carbon dioxide emission can be calculated (see table I-3)

Table I- 3 Shanghai's Carbon Dioxide Emission and its Composition (2000-2008)

Year	Carbon Dioxide Emission (10 000 tons CO_2)	Of Which			
		Coal	Oil	Natural Gas	Electricity outside Shanghai
2000	14394	10423	3902	55	13
2001	15266	10868	4188	71	140
2002	15970	10823	4803	93	251
2003	17417	11424	5446	107	440
2004	19357	11679	6511	230	937
2005	21094	12338	6820	403	1534
2006	23157	12059	8320	543	2235
2007	25010	12694	8851	598	2868
2008	25989	13330	9028	646	2986

23 Under standard temperature and pressure, the density of natural gas is 0.7-0.9 kg/ m^3 , so we choose the average value, i.e. 0.8 kg/ m^3 .

24 The emission factor of electricity is calculated by the Fudan University's Project of "Roadmap of Shanghai's Low Carbon City".

Appendix II Growth Rate and the Share of Primary, Secondary and Tertiary Industry

In Chapter 3, we use the assumptions on the growth rate of final consumption, gross capital formation and net outflows of goods and services to estimate GDP and its growth rate in Shanghai from 2010 to 2020. For the growth rate and the share of primary, secondary and tertiary industry, we firstly need to calculate their output at the constant price of 2000 (see table II-1).

Table II- 1 Primary, Secondary and Tertiary Industry (at the constant price of 2000)

Year	Primary Industry (100 million yuan)	Secondary Industry (100 million yuan)	Tertiary Industry (100 million yuan)
2000	76.68	2207.63	2486.86
2001	78.93	2431.69	2761.32
2002	81.44	2680.42	3106.08
2003	79.75	3158.79	3350.91
2004	77.79	3628.19	3819.42
2005	81.82	3971.62	4329.69
2006	83.83	4441.33	4922.58
2007	88.72	4853.08	5942.02
2008	94.87	5164.40	6680.32
2009	97.72	5152.95	7667.76

Data Source: Shanghai Statistical Yearbook 2010

Then growth rates of primary, secondary and tertiary industry are assumed under transformation scenario, moderate intervention scenario and strong intervention scenario (see table II-2 and II-3).

Table II- 2 Assumptions on Growth Rate of Primary, Secondary and Tertiary Industry

(Transformation and Moderate Intervention Scenario)

	Primary Industry	Secondary Industry	Tertiary Industry
2009-2010	1.30%	5.50%	11.00%
2011-2015	1.20%	5.50%	9.00%
2015-2020	0.90%	4.50%	7.50%

Table II- 3 Assumptions on Growth Rate of Primary, Secondary and Tertiary Industry (Strong Intervention)

	Primary Industry	Secondary Industry	Tertiary Industry
2009-2010	1.30%	5.50%	11.00%
2011-2015	1.20%	4.50%	9.00%
2015-2020	0.90%	4.00%	7.50%

Through the above assumptions, the share of primary, secondary and tertiary can be calculated (see table II-4 and II-5).

Table II- 4 Share of GDP by Industry (Transformation and Moderate Intervention Scenario)

	2000	2010	2015	2020
GDP (at the constant price of 2000) (100 million yuan)	4771.17	14132.60	20355.56	28428.69
Primary Industry	1.61%	0.70%	0.52%	0.39%
Secondary Industry	46.27%	38.70%	34.99%	32.41%
Tertiary Industry	52.12%	60.59%	64.49%	67.20%

Table II- 5 Share of GDP by Industry (Strong Intervention Scenario)

	2000	2010	2015	2020
GDP (at the constant price of 2000) (100 million yuan)	4771.17	14132.60	19789.65	26484.43
Primary Industry	1.61%	0.70%	0.53%	0.40%
Secondary Industry	46.27%	38.70%	33.92%	30.36%
Tertiary Industry	52.12%	60.59%	65.56%	69.24%

Finally, output by industry and its growth rate can be estimated again based on the share of GDP (table II-4 and II-5) and GDP calculated by final consumption, gross capital formation and net outflow. The growth rates of primary, secondary and tertiary industry are illustrated in the following table.

Table II- 6 Growth Rate of Primary, Secondary and Tertiary Industry (Transformation and Moderate Intervention Scenario)

	2000-2005	2005-2010	2010-2015	2015-2020
Primary Industry	1.35%	4.01%	1.13%	1.17%
Secondary Industry	12.51%	6.61%	5.42%	5.28%
Tertiary Industry	11.75%	14.61%	8.92%	7.79%

Table II- 7 Growth Rate of Primary, Secondary and Tertiary Industry

(Strong Intervention Scenario)

	2000-2005	2005-2010	2010-2015	2015-2020
Primary Industry	1.35%	4.01%	0.89%	0.59%
Secondary Industry	12.51%	6.61%	4.18%	3.68%
Tertiary Industry	11.75%	14.61%	8.66%	7.17%