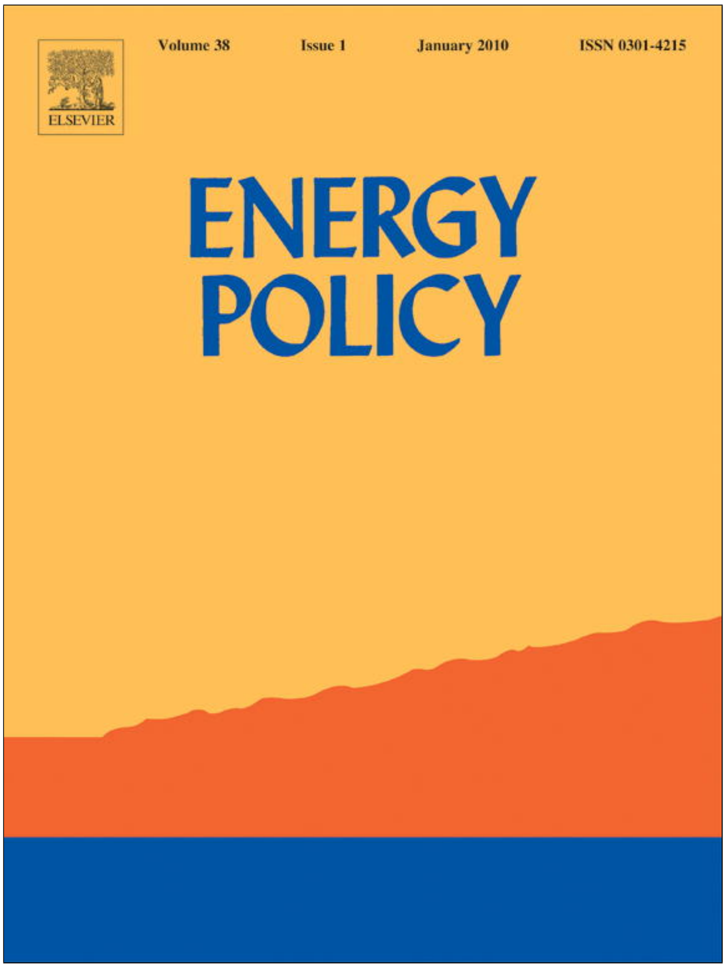
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Communication

The strategy of energy-related carbon emission reduction in Shanghai

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A B S T R A C T

This paper presents a system analysis approach on carbon emission reduction at urban level, taking Shanghai as a case. Shanghai's current carbon emission was analyzed based on survey. The prospective carbon emission of Shanghai in 2010 and 2020 were estimated based on scenarios analysis. The main results are: (1) the primary energy consumption of Shanghai shows a continuously increasing trend in recent decades; (2) the energy consumption for production is where the majority of Shanghai's energy consumption is being used; (3) among the total energy consumed, secondary industry energy consumption occupies the biggest share; (4) computations indicate that Shanghai's current carbon emission steadily increased from 1990 to 2005 and reached 58.05 Mt C-eq in 2005, a factor of two times its 1990 emission; (5) if Shanghai can realistically meet the target of the 11th Five-Year Plan, the carbon emission reduction will reach to 17.26 and 111.04 Mt C-eq in 2010 and 2020, respectively, which represents a reduction of nearly 46% below its current growth trajectory in 2020. Based on these results, three strategic suggestions for developing low-carbon economy in Shanghai have been proposed, which can also be applied to other similar cities in China.

1. Introduction

Climate change is a significant global problem that affects the survival and development of all human beings (IPCC, 2001; IPCC, 2005; IPCC, 2007; United Nations, 1992; United Nations, 1997). China has participated actively in the implementation of the *United Nations Framework Convention on Climate Change* and the *Kyoto Protocol*, and promulgated *China's National Climate Change Programme* on June 1, 2007. China also contributed a lot to the formation of Bali plan in 2008, which will guide the future global actions responding to climate change.

The existing literature pays most attention to China's carbon emission at national level (China National Development and Reform Commission, 2007). While city is an important and basic unit to perform energy and environmental strategies on carbon emission reduction, it is necessary to consider how to control carbon emission at urban level. As one of China's developed cities, Shanghai is also one of the country's largest emitters of greenhouse gases. Consequently, Shanghai will be under pressure to control its CO_2 production when China commits to carbon emission reduction. Additionally, as a coastal city adjacent to Yangtze River estuary and the East China Sea, Shanghai is also likely to face significant challenges of possible rises in sea level caused by climate change. Research on Shanghai's ambient air pollution and related energy policy are discussed in some studies (Chen and Wang, 2003; Chen et al., 2007), which outlines Shanghai's CO_2 emission reduction that benefits from China's energy policy. This study proposed a system analysis approach on energy-related carbon emission estimation and reduction policy analysis based on present studies, which can be a reference and guidance for Shanghai and similar metropolis cities in China to take proactive steps to combat climate change.

2. Methodology

Energy structure is much easier to be changed at urban level, compared with that of country level. Besides, total energy consumption is more likely to be controlled at urban level because of more direct governance. Based on these features at different levels, this paper presented a system methodology on carbon emission estimation and reduction policy analysis at urban level, as shown in Fig. 1.

System analysis approach is used as a basic method to study the relationship among economy, energy and environment in Shanghai. According to the statistics data released by Shanghai Municipal Government, Shanghai's energy-related carbon emission is found to be closely related to Shanghai's economy structure, energy consumption structure and carbon emission coefficient. Therefore, these three factors were analyzed firstly. Based on the analysis results, Shanghai's carbon emission history was calculated and presented. According to the historical track of Shanghai's carbon emission and national and local regulations,

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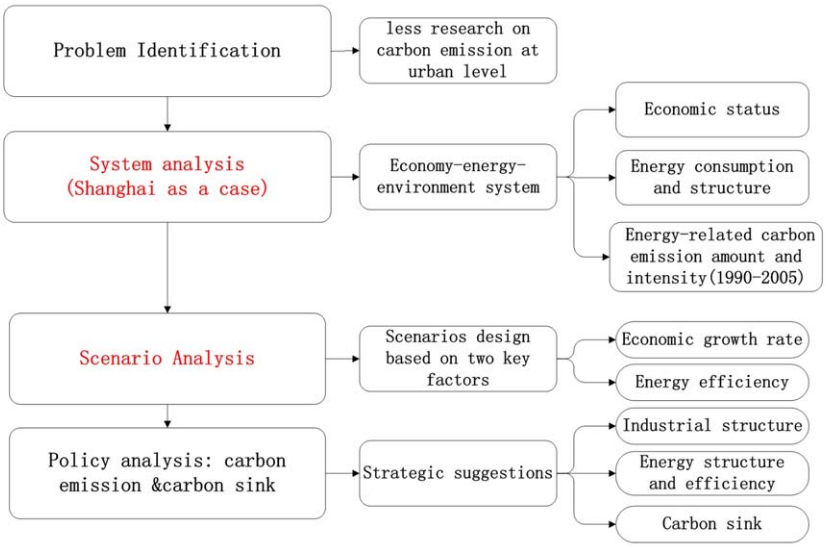

Fig. 1. Flowchart of system analysis approach for carbon emission reduction.

Fig. 2. Location of Shanghai.

future carbon emission of Shanghai was projected through scenario analysis, considering both economic growth and energy efficiency factors. In the end, strategic policy suggestions are proposed based on the scenario analysis results.

3. Case study of shanghai

3.1. Background of Shanghai

Shanghai, with an area of 6340.5 km^2, is located along the coast of the East China Sea and in the delta plain of the Yangtze River (Fig. 2). It is known as the economic center of China and has maintained rapid economic growth in recent years. For instance, Shanghai's gross domestic product (GDP) rose from 16.67 billion US$ (78.17 billion RMB[1]) in 1990 to 113.28 billion US$ (916.41 billion RMB[2]) in 2005, with an average annual increase of GDP growth rate by 13.6% in US$ (17.8% in RMB) during the past 15 year period.

3.2. Energy consumption

According to the Shanghai Statistics Yearbook 2006, the total energy consumption of Shanghai from 1985 to 2005 revealed a nearly 3 times increase, which reached 80.7 million tons standard coal in 2005 (Fig. 3). Referred to Dolf and Chen (2001), we find that Shanghai's actual energy consumption in 2005 exceeded Gielen's estimation, which implies that Shanghai's growth rate in energy use grew faster than predicted.

In Fig. 4, the data shows that over 90% of Shanghai's energy is consumed by its industry sector (primary, secondary and tertiary industries), which is much more than the 10% energy consumption from family life aspect. Here, the primary industry refers to agriculture, forest, herding and fishing sector; the secondary industry mainly includes mining sector, manufacturing sector, production and distribution sector of electricity, gas and water, construction sector; and the tertiary industry usually means service sector.

From Fig. 4, it can also be seen that the energy consumption proportion from the secondary industry decreased gradually from 80% to 60%, as the largest contribution part to the total energy consumption increase from 1990 to 2005. Among the energy use of secondary industry, the traditional manufacturing industry with the high pollution emission characteristics was the biggest one. Therefore, higher the energy consumption is, the more pollution will be generated. From 1990 to 2005, the tertiary industry energy consumption proportion grew from 13% in 1990 to 29% in 2005, which is an important signal of energy consumption transition among different economy sectors.

3.3. Energy structure

Shanghai's energy structure from 2001 to 2005 is illustrated in Fig. 5. It can be seen that coal and oil still occupy the biggest part in Shanghai's energy structure. Although there is a decreasing trend in coal use, the proportion of coal in Shanghai's total energy consumption was still at 53% in 2005.

As shown in Fig. 6, coal constituted less than 30% of the energy consumed by major developed countries and regions in 2005 while in Shanghai it was 53% and less than China national level. It

[1] The exchange rate of 1990 is about 4.7221 RMB for 1 US$.
[2] The exchange rate of 2005 is about 8.0896 RMB for 1 US$.

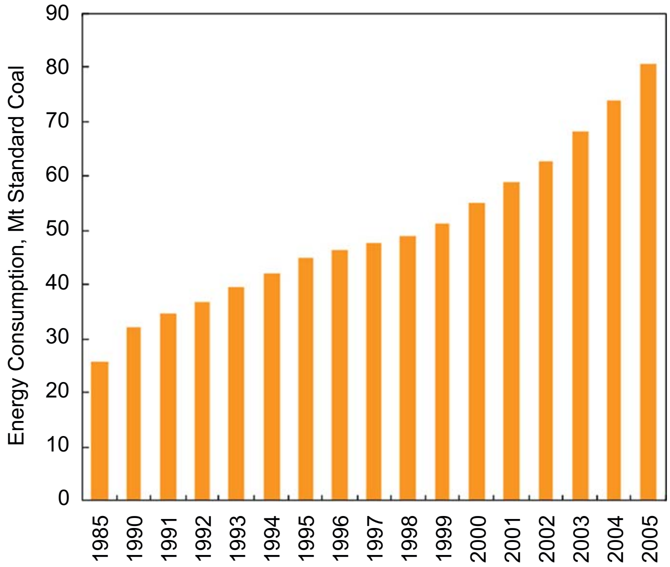

Fig. 3. Total energy consumption in Shanghai (1985, 1990–2005).

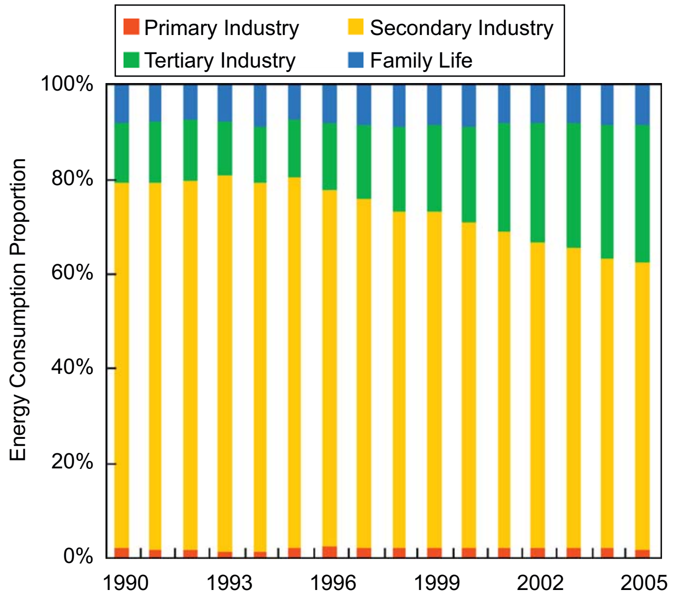

Fig. 4. Proportion of energy consumption for production and family life (1990–2005).

is also clear that more natural gas is used in developed countries and regions, while in Shanghai natural gas is only used as a supplementary energy. Shanghai's energy structure, which heavily relies on coal, creates a significant challenge for carbon reduction, since the CO_2 emission factor of coal is 90–100 tCO_2/TJ while that of dry natural gas is 54–58 tCO_2/TJ (IPCC,1996). However, the coal consumption proportion of Shanghai is less than that of China. As a matter of fact, it is very difficult for China to change its energy structure in a short term, and it is the same with Shanghai.

3.4. Energy-related carbon emission of Shanghai

As shown in Fig. 7, Shanghai's carbon emission from 1990 to 2005 increased steadily to 58 Mt Carbon equivalent (C-eq) in 2005. These figures represent the carbon emission from the combustion of various fossil fuels and were calculated using recommended coefficients of carbon emission for China (China National Development and Reform Commission, 2007; Shanghai Statistics Bureau, 2007; ORNL, 1990). Fortunately, the carbon emission intensity decreased continuously.

Further analysis from Fig. 8 shows that the proportion of coal-fired carbon emission declined from 84% in 1994 to 57% in 2005. The per capita carbon emission (PCCE)[3] of Shanghai is almost 2.9 times as that of China and 2.4 times as that of the world. Meanwhile, PCCEs of many developed countries except USA, Canada and Australia are lower than that of Shanghai. Therefore, there is still much potential for Shanghai to reduce its PCCE.

4. Scenario analysis

4.1. Scenario building

To estimate Shanghai's future carbon emission, we created twelve scenarios divided into two groups that were based on Shanghai's economic growth and energy intensity. Using year 2005 as a baseline, we generated short-term (2010) and long-term (2020) projections for each scenario. In the first group, the annual average GDP growth rate is kept in 10% (consistent with the 11th

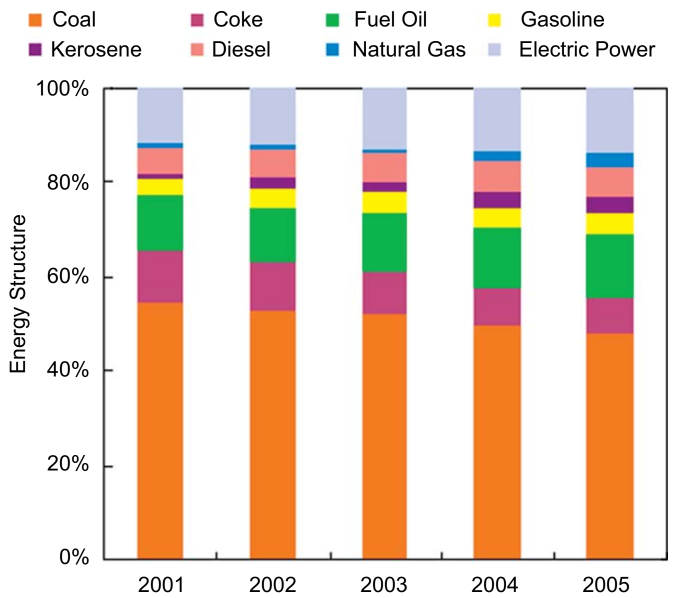

Fig. 5. Energy structure of Shanghai (2001–2005).

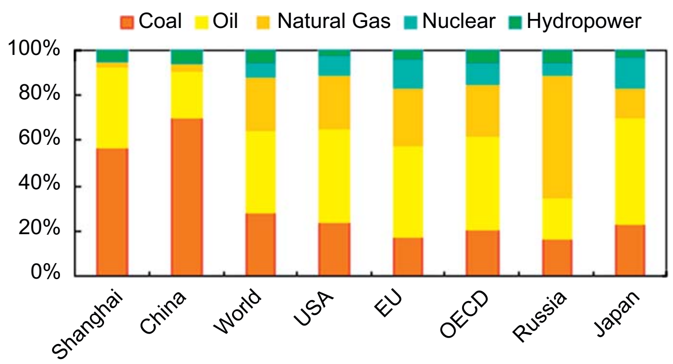

Fig. 6. Comparison of energy consumption structure in the World in 2005.

[3] The per capita carbon emission of Shanghai in 2004 is estimated by the resident population, which is 17.42 million.

Five-Year Plan of Shanghai) from 2005 to 2020, with the annual average descending rate of unit GDP energy consumption from 5% to 0%. In the second group, the annual average GDP growth rate is kept in 5% from 2005 to 2020, also with the annual average descending rate of unit GDP energy consumption from 5% to 0%.

The data used for calculation (GDP and energy consumption) of these twelve scenarios are shown in Table 1 and carbon emission for each scenario is shown in Fig. 9.

4.2. Results and discussions

Under the assumption that the GDP growth rate is unchanged, different energy efficiencies lead to great differences in carbon emission. Taking the result of year 2020 as an example, the carbon emission in S6 are 2.2 times as that in S1. Regarding scenarios with the same energy intensity but different annual GDP growth rate, great differences can be also found clearly. For instance, the carbon emission for the high rate of growth (S1) is 2.0 times that of the low rate (S7) in 2020. When the rate of the economic growth is restrained, and at the same time energy efficiency is improved, the reduction of carbon emission is staggering. For example, carbon emission in S7 is only 23% of that in S6 (in year 2020).

According to Shanghai's 11th Five-Year Plan for economic and social development (2005–2010) (hereinafter referred to as 11th Five-Year Plan), Shanghai will achieve an annual average economic growth rate of more than 9%. Meanwhile, the unit GDP energy consumption in 2010 will decrease by 20% than that at the end of the "10th Five-Year", with an annual average decline of 4%. If after 2010 the rate of the economic growth and the decline of unit GDP energy consumption are kept at 10% and 4%, respectively, scenario S2 would be of the mostly likely outcome in 2010 and 2020. Compared with scenario S6, in which the economic growth rate and energy intensity are kept at the same level as that in 2005, Shanghai would reduce carbon emission by 17.26 Mt C-eq and 111.04 Mt C-eq in 2010 and 2020, respectively, in the case of scenario S2. Clearly, if Shanghai can realistically meet the targets of the 11th Five-Year Plan, the reduction of carbon emission would be significant.

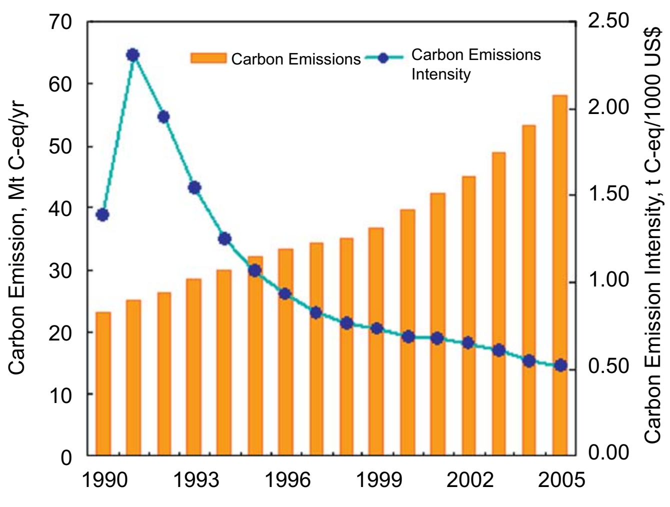

Fig. 7. Variation of the carbon emission amount and intensity in Shanghai (1990–2005).

Nowadays, clean coal technology is being considered as an important way to save energy in Shanghai. It is reported that there are a few demonstrations of clean coal technology, such as Shenhua clean coal research center. Meanwhile, eco-efficiency was greatly improved during the last two decades. However, it should be noted that the eco-efficiency of industry in Shanghai is still far below the advanced international level. Concerning demand side management, exploration of an energy management mechanism by contract was already conducted in Shanghai, 26 energy-saving service companies were established, and 181 projects of various kinds carried out, annual energy-saving of 110,000 tons standard coal achieved, and 60,000 kW power load reduced. Study of energy-saving by voluntary agreement was conducted in such industries as steel, power, petrochemical and chemical industries. A mechanism for voluntary purchase of electricity generated from renewable energy was established, thus making Shanghai the first city in developing countries to institute a green electrical power mechanism. It must be pointed out that the proportion of renewable energy used was not taken into account in this scenario analysis due to data limitation. At present, Shanghai has already begun to develop wind power and solar power. In future, Shanghai will make more effort to promote utilization of renewable energy. For example, vigorous efforts will be made to push the construction of wind-driven power fields at sea and on the shoals, with an installed capacity of 200,000–300,000 kW. And the exploitation of solar energy and bio-energy in the countryside will be promoted. If Shanghai can successfully move toward renewable energy targets in the future, its carbon emission can be significantly reduced.

5. Policy implications

Based on the historical and future estimation of Shanghai's carbon emission, it is clear that more special attentions should be paid to achieve carbon emission reduction. As one of the most developed cities in China, Shanghai should take more responsibilities to combat

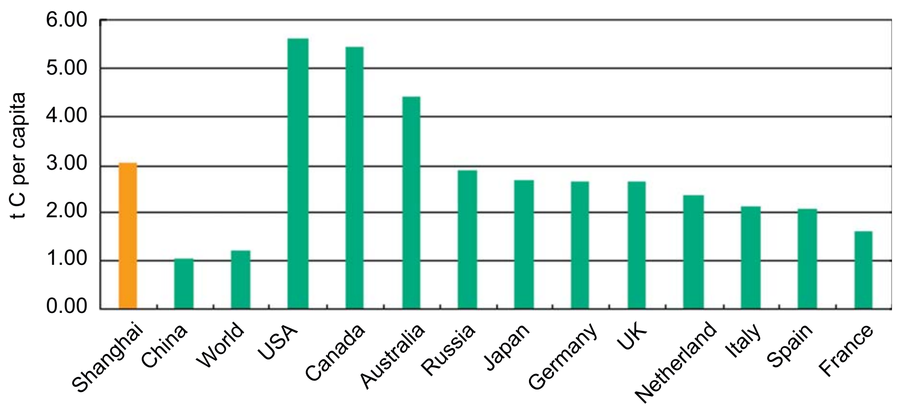

Fig. 8. Comparison of per capita carbon emission in the world (2004). Data source: United Nations Development Programme, 2008.

Table 1
GDP and energy consumption data used for calculation of different scenarios.

Scenario	GDP growth rate/%	Declination rate of unit GDP energy consumption/%	GDP of Shanghai/billion US$			Energy consumption/ten thousand tons standard coal		
	2005–2020	2005–2020	2005	2010	2020	2005	2010	2020
S1	10	5	113.28	182.44	473.21	8069.43	10049.72	15606.91
S2	10	4	113.28	182.44	473.21	8069.43	10589.91	18261.28
S3	10	3	113.28	182.44	473.21	8069.43	11153.07	21332.35
S4	10	2	113.28	182.44	473.21	8069.43	11739.95	24880.20
S5	10	1	113.28	182.44	473.21	8069.43	12351.28	28972.81
S6	10	0	113.28	182.44	473.21	8069.43	12987.81	33687.03
S7	5	5	113.28	144.58	235.51	8069.43	7964.11	7767.23
S8	5	4	113.28	144.58	235.51	8064.41	8392.19	9088.25
S9	5	3	113.28	144.58	235.51	8064.41	8838.48	10616.66
S10	5	2	113.28	144.58	235.51	8064.41	9303.56	12382.35
S11	5	1	113.28	144.58	235.51	8064.41	9788.02	14419.16
S12	5	0	113.28	144.58	235.51	8064.41	10292.46	16765.33

global climate change. Based on this system analysis research, three strategic policy suggestions have been proposed to facilitate the development of low-carbon economy in Shanghai.

5.1. *Improve industrial structure*

Since carbon emission in Shanghai mainly originated from industrial activities, the improvement of industrial structure is the primary option for Shanghai. Giving priority to the development of modern service industries and advanced manufacturing industry is the focus of optimization of the industrial structure in Shanghai. Shanghai should keep on increasing the proportion of the industries with high value added and less energy consumed. Furthermore, Shanghai should also upgrade the level of service industry while speeding up the development of tertiary industry.

Meanwhile, Shanghai's 11th Five-Year Plan for Saving Energy stated that "innovation of mechanisms shall be promoted so as to provide support for saving energy, and the fundamental role of market in resource distribution shall be improved further". Thus, innovative market-oriented mechanism for industrial structure improvement should also be an important way to achieve carbon emission reduction.

5.2. *Optimize energy structure and efficiency*

Energy structure optimization is an essential and long-term way to achieve net carbon emission reduction. As a developed city in China, Shanghai should actively build a diverse and efficient energy supply and consumption system with the characteristics of environment and climate friendly.

The traditional energy mix (mainly including coal and oil) should gradually shift toward one with a lower carbon emission per energy output. For example, the share of coal should be reduced to less than 50% of the total primary energy by 2010. Meanwhile, renewable energy should be developed further as a low-carbon strategy. Shanghai is rich in wind energy sources, especially in Chongming Island and along the coastal region of Nanhui District and Fengxian District. The development of wind power has high potential in Shanghai. At the same time, Shanghai should further develop high performance and low-cost photovoltaic battery technology, and solar thermal power generation technologies.

On the other hand, efforts should be spent on enhancing the current energy use efficiency. More attention should be paid to

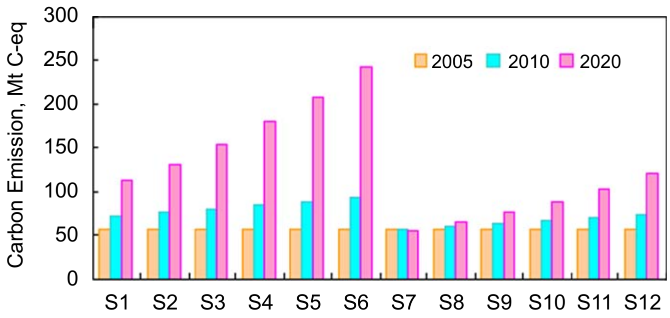

Fig. 9. Carbon emission for Shanghai's twelve scenarios.

the green energy techniques and demand side management. Cap-trade mechanism can be a possible way to gradually improve energy efficiency with low cost. Related parties should keep open minds to facilitate the improvement of energy efficiency.

5.3. *Strengthen construction of carbon sink*

Although this paper mainly talks about carbon emission reduction, carbon sink construction is a necessary way to reduce unavoidable emissions. Forest, greenbelt, wetland and cropland are important carbon sinks in Shanghai. The enhancement of carbon sinks is absolutely necessary to reduce net carbon emission in Shanghai.

The areas of forest and greenbelt should be expanded and the structure of forest and greenbelt should be optimized according to local features. Meanwhile, the protection of wetlands, especially Chongming and Nanhui wetlands, should be strengthened by restoring the ecological habitat and enhancing the management of wetlands. The implementation of stringent cropland protection system is also necessary to protect soil carbon sink.

6. Conclusion

This paper presents a system analysis approach on carbon emission reduction at urban level, taking Shanghai as a case. The primary energy consumption of Shanghai shows a continuously increasing trend in the past 15 years. The energy consumption for production is where the majority of Shanghai's energy consumption is being used. Among the total energy consumed, industrial energy consumption occupies the biggest share. Results from this study indicate that Shanghai's energy-related carbon emission steadily increased from 1990 to 2005 and reached 58.05 Mt C-eq in 2005, nearly two times of its 1990 emission.

Based on twelve scenarios with different economic development and energy intensity features, Shanghai's future emission was projected. The results show that if Shanghai can realistically meet the target of the 11th Five-Year Plan, the carbon emission reduction will reach to 17.26 Mt C-eq in 2010 and 111.04 Mt C-eq in 2020, respectively, which represents a reduction of nearly 46% below its current growth trajectory in 2020.

As one of the most developed cities in China, Shanghai should take more responsibilities and its future also depends on the present actions. To do so, three strategic policy suggestions have been proposed to reduce future carbon emission: (1) improving the industrial structure; (2) optimizing energy structure and efficiency; and (3) strengthening carbon sink construction.

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