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Energy demand and carbon emissions under different development scenarios for Shanghai, China

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ABSTRACT

In this paper, Shanghai's CO_2 emissions from 1995 to 2006 were estimated following the IPCC guidelines. The energy demand and CO_2 emissions were also projected until 2020, and the CO_2 mitigation potential of the planned government policies and measures that are not yet implemented but will be enacted or adopted by the end of 2020 in Shanghai were estimated. The results show that Shanghai's total CO_2 emissions in 2006 were 184 million tons of CO_2. During 1995–2006, the annual growth rate of CO_2 emissions in Shanghai was 6.22%. Under a business-as-usual (BAU) scenario, total energy demand in Shanghai will rise to 300 million tons of coal equivalent in 2020, which is 3.91 times that of 2005. Total CO_2 emissions in 2010 and 2020 will reach 290 and 630 million tons, respectively, under the BAU scenario. Under a basic-policy (BP) scenario, total energy demand in Shanghai will be 160 million tons of coal equivalent in 2020, which is 2.06 times that of 2005. Total CO_2 emissions in 2010 and 2020 in Shanghai will be 210 and 330 million tons, respectively, 28% and 48% lower than those of the business-as-usual scenario. The results show that the currently planned energy conservation policies for the future, represented by the basic-policy scenario, have a large CO_2 mitigation potential for Shanghai.

1. Introduction

Cities are centers of high population density and large energy consumption throughout the world (WEO, 2008). Urban activities, such as urban transport, industrial activities, solid waste disposal, domestic fuel use and power generation generate a considerable amount of greenhouse gases (Dhakal, 2004; Dhakal, 2009; Rashmi et al., 2007; WEO, 2008). Global urban population has continued to increase in recent decades, which further accelerates the growth of energy consumption, because the per capita energy consumption will also increase in cities in developing countries, where most of the future population growth is going to occur (WEO, 2008; UN, 2007). Therefore, the impact of cities on global carbon emissions is becoming increasingly important (Marshall, 2008; WEO, 2008). In China, urban areas already contribute 84% of total commercial energy consumption and 75% of total energy consumption (in 2006) and are responsible for 85% of energy related CO_2 emissions (Dhakal, 2009; WEO, 2008). Between 2008 and 2030, 300–450 million more people will be added to the urban population in China (UN, 2007; MGI, 2008). Thus, the sources of greenhouse gases (GHGs), as well as the opportunities for controlling their emissions, exist at the local level (Wilbanks and Kates, 1999). In recent years, a number of cities have already developed GHG emission inventories and have published action plans to curtail GHG emissions, which will play a positive role in reducing global warming (Australia, 2007; Bangkok, 2007; Berkeley, 1998; Brighton Hove, 2006; Calgary, 2006; Cape Town, 2006; Darebin, 2007; Exeter, 2008; Gloucester, 2007; Hamilton, 2006; Coventry, 2007; Green LA, 2007; Lincoln, 2005; London, 2007; Melbourne, 2006; Michael 2007; Nelson, 2008; Ottawa, 2004; Oxford, 2005; Peterborough, 2007; Plymouth, 2008; Seattle, 2006; Singapore, 2008; Tokyo, 2007; Toronto, 2007; Vancouver, 2005; Wellington, 2007; Worcester, 2006).

Shanghai is an important economic center and the front-runner in the economic development of China. It hosts around 18 million residents and occupies 6340 sqkm. Shanghai's economic growth rate has exceeded 10% per annum for the past 16 years. As a result, the GDP and per capita GDP of Shanghai reached 1037 billion Yuan and 57,695 Yuan (7236 USD, 2006 average exchange rate, 1US$ = 7.9735 Yuan), respectively, in 2006. This represents

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an increase of almost two times from 2000 to 2007 alone (Shanghai Statistical Yearbook, 1996–2007). Such a fast pace of economic growth drives high growth in energy consumption (and thus CO_2 emissions) due to the rapid changes in the underlying drivers, such as the urban population, vehicle stock, lifestyle changes, proliferation of energy consuming technologies, and production and consumption activities. Despite a number of previous studies (Chen and Du, 2002; Chen, et al., 2006a, 2007b; Dhakal, 2004, 2009; Gnansounou, et al., 2004; Wu, et al., 1997), a detailed inventory of CO_2 emissions and future projections in light of recent economic and policy developments are lacking for Shanghai. In the near future, Shanghai is expected to continue its rapid growth trend, although it is possible that the growth rate will decrease to some degree. Thus, it is also likely that energy demand and CO_2 emissions will also increase considerably. Clearly, energy conservation and energy efficiency strategies are of great importance for Shanghai, because they can simultaneously address energy security, local pollution control and CO_2 mitigation.

Therefore, in this study, we have estimated the past and the present energy consumption and CO_2 emissions in Shanghai and evaluated the benefits of the planned energy conservation policies for CO_2 mitigation if adopted in the future. This paper also outlines a detailed inventory of CO_2 emissions and future trends, which will be useful for Shanghai in determining actions for the mitigation of climate change. As the title of this paper suggests, we only estimated the inventory for CO_2 emissions from energy uses (including industrial activities), which is not an overall assessment of the GHG emissions of Shanghai. Other GHGs, like fugitive methane emissions from local landfills, agricultural operations and wastewater treatment operations, are not included in this study.

2. Methodology and data

2.1. Energy consumption in Shanghai

For this analysis, the total and sectoral energy data for 1995–2006 were obtained from the Energy Balance Tables of the Shanghai Statistical Yearbook on Industry, Energy and Transport. The energy consumption in Shanghai is divided into three parts: energy processing and conversion, loss and end use. The sector classification in Shanghai's energy data includes: primary industry (such as farming, forestry, animal husbandry and fishery), secondary industry (such as manufacturing industries and the construction sector), tertiary industry (such as transportation, storage, post and communications, wholesale, retail sales, catering, trade and others) and households. These statistical data are compiled by the Shanghai Statistical Bureau.

2.2. Estimation of CO_2 emissions

The global rise in anthropogenic sources of CO_2 emissions is due to the use of fossil fuels and changes in land use (Chen, et al, 2004; GCP, 2008). Furthermore, the major CO_2 sources in China are energy consumption and industrial processes like cement production and glass production. For this study, the estimation of CO_2 emissions from energy consumption and industrial activity in Shanghai were carried out. Following IPCC guidelines, energy consumption included energy processing, conversion and the final consumption. Industrial activities that result in CO_2 emissions are cement production, glass production and the desulfurization process.

CO_2 emissions from energy consumption were calculated by Eq. (1), as shown below.

$$E = \sum_i \sum_j A_{i,j} \times NCV \times C_{i,j} \times O_{i,j\bullet} \times 44 \div 12 \qquad (1)$$

where E is the total CO_2 emissions from energy consumption (ton); $A_{i,j}$ the amount of consumption of fuel j in sector i (million tons or million m^3 for natural gas); NCV the net calorific value; $C_{i,j}$ is the carbon emission factor of fuel j in sector i (tC/TJ), and $O_{i,j}$ the carbon oxidation rate of fuel j in sector i. Fuel types for this paper include the fuel categories in the energy balance tables of Shanghai. They are hard coal, washed coal, coke, coke oven gas, other gas, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gases, refinery gas, natural gas, other oil products and other coke products. The CO_2 emissions for each end-use sector were estimated, and the proportion of energy consumed in energy processing and conversion were determined. The end-use sectors include agriculture, construction, industry, transportation, commercial and service industries and residential use. Industry was further divided into subsectors, including steel, nonferrous metal, construction material, basic chemical, petrol chemical, pulp and paper manufacturing, processing industries and others. Following a territorial principle, emissions from heat and electricity produced inside Shanghai were estimated for the paper, while those from imported electricity were not considered. In this paper, the default value of the oxidation rate (100%) was applied to estimate emissions.

For this study, the energy consumption data during 1995–2006 were taken from the Shanghai Statistical Yearbook on Industry, Energy and Transport (Shanghai Statistical Yearbook, 1996–2007). The net calorific values of various energy types were taken from the China Energy Statistical Yearbook, 2006 (China Statistics Press, 2007). The emission factors for carbon were taken from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006).

CO_2 emissions from industrial activities were calculated according to the following equation.

$$E = \sum_i A_i \times EF_i \qquad (2)$$

where, E is the CO_2 emissions from industrial activity (ton); i is the technical craft; A_i is the activity data of the ith technical type (ton), and EF_i, is the emission factor of the ith technological type. The types of technology considered were cement production, glass production and the desulfurization process. For these estimations, the activity data were taken from the Shanghai Statistical Yearbook, while the emission factors were taken from the "2006 IPCC Guidelines for National Greenhouse Gas Inventories".

2.3. Scenario analysis

In order to demonstrate the future energy consumption and CO_2 emissions, and to evaluate the benefits of energy conservation policies to mitigate carbon emissions, two scenarios were analyzed in this study; the business-as-usual (BAU) scenario and the basic-policy (BP) scenario. These scenarios are primarily governed by four factors: economic growth, population growth, the structure of the economy and the energy structure.

2.3.1. Business-as-usual (BAU) scenario

The BAU scenario is a high economic growth case, which assumes that the past trends continue in the future and no new policies for energy saving and environmental protection will be implemented. The BAU scenario does not take into account the policies that have been published, but not yet implemented. The major assumptions for the BAU scenario are as follows:

2.3.1.1. Economic development. As an economic center of China, Shanghai has experienced a double-digit economic growth rate for the past 16 years. The annual average growth rate of Shanghai from 1993 to 2006 was 12%. However, there are strong signs that the global economy, which had expanded briskly in recent years, is slowing, partly as a consequence of higher prices for energy and other commodities and the financial crisis that began in 2007 (WEO, 2008). There are signs that the economic activities of developing Asian countries are now beginning to slow, and GDP growth in all regions is expected to fall, though non-OECD countries will continue to outpace the remainder of the world (WEO, 2008). In view of such slackness in the economy, we assumed that the economic growth rate in the BAU scenario continues to be 12% during 2008–2010, but is 10% during 2010–2015 and 8% during 2015–2020. Under this assumption, the GDP in Shanghai will reach 1648 and 3900 billion Yuan in 2010 and 2020 (in 2005 prices), respectively.

2.3.1.2. Population growth. Population growth can affect the size and composition of energy demand, directly and through its impact on economic growth and development (WEO, 2008). Shanghai's resident population rose from 13.34 million to 18.15 million from 1990 to 2006. Of this population increase, the majority (83% or about 4 million) was from the increase in the floating population (people who come from outside and stay in Shanghai for more than half a year). In 2006, Shanghai's floating population was 4.5 million, and thus, the rise in the size of the floating population will largely determine the future population of Shanghai. In order to project the population for the BAU scenario, we assumed that the trend for an increase in the registered population will prevail (at an average annual growth rate of 0.7%, 1980–2006). For the floating population, the annual growth rate peaked in 1988 (growth rate of 65% in 1990) and since then has decreased, but was quite volatile before 2003. Through expert consultations and our own subjective judgment, we assumed that the average annual growth rate for the floating population will be 6.7% until 2020 (the average of 2004–2007). These growth rates indicate that the total population in Shanghai will reach 26 million in 2020.

2.3.1.3. Economic structure. The BAU scenario assumes that the current patterns in the industrial structure will be maintained, and the division among the energy-intensive sectors will be the same as before; this implies no change compared to the structure in 2006. Five energy-intensive industrial subsectors were included in this calculation and account for the bulk of industrial energy consumption and the related carbon dioxide emissions. The five subsectors were iron and steel, chemical, building material, papermaking and the supply of heat, electricity and water. In 2006, the shares of the primary, secondary and tertiary industries were 0.90%, 48.51% and 50.59%, respectively. Within secondary industry, the share of the energy-intensive subsectors was 26.63% in 2006.

2.3.1.4. Energy structure. The BAU scenario assumes that the energy structure of Shanghai will not change in the future. Coal remains the major source of energy. The share of coal, oil and natural gas will remain at 57.1%, 39.5% and 3.4% of the total primary energy sources, respectively, as in 2006.

2.3.2. Basic-policy (BP) scenario

The BP scenario reflects a shift towards a more sustainable energy pathway that is realized by policies and measures aimed at increasing energy efficiency and reducing energy consumption. The basis of the BP scenario is the planned government policies and measures that are not yet implemented, but will be enacted or adopted by the end of 2020 in contrast to the past trends. However, the possible, the potential or the likely future policy actions are not considered in BP scenario. Therefore this scenario does not include new policies. This scenario, in contrast to BAU, has the potential energy and CO_2 savings associated with the planned policies. This scenario is mostly based on the 11th Five-Year Plan of Shanghai. The major assumptions and the basis for the BP scenario are as follows:

2.3.2.1. Economic development. Economic growth is by far the most important determinant of the overall demand for energy services (WEO, 2008). Thus, assumptions concerning economic development will influence estimates of energy demand and CO_2 emissions.

The 11th Five-Year Plan of Shanghai's National Economic Development (Shanghai Municipal Government, 2006a) envisions that Shanghai's economic growth rate during 2006–2010 will be more than 9%, and the GDP in 2010 will reach around 1500 billion Yuan. According to the WEO (2008), China is assumed to grow at 9.2% per year between 2006 and 2015 and at 6.1% between 2006 and 2030. The WEO (2008) indicates that the GDP growth in all regions is expected to fall in the next few decades.

Considering that Shanghai is one of the most developed cities in China and its economic growth rate is higher than the national average, we assume that the GDP in Shanghai will grow at a rate of 10% during 2006–2010, 8% during 2010–2015 and 6% during 2015–2020. Based on this assumption, the GDP of Shanghai will reach 1561 and 3070 billion Yuan in 2010 and 2020, respectively.

2.3.2.2. Population growth. There are two local plans regarding population control for Shanghai. According to "The 11th Five-Year Plan of Shanghai Population and Family Planning Development" (Shanghai Municipal Government, 2007a), the population in Shanghai should be consistent with the carrying capacity of the urban resources and the environment and with the social and economic development. As envisioned in the plan, the population in 2010 will be controlled at around 19 million. Another older plan titled "Shanghai General Planning (1999–2000), Action Plan in Mid and Short Term" envisions the total population in 2020 to be around 20 million.

Based on the study and plans mentioned above, we assume that the total population in 2010 and 2020 in Shanghai will be around 19 and 20 million, respectively. This assumption is reasonable and perhaps acceptable, although there are uncertainties about the possibilities to control the population size.

2.3.2.3. Economic structure. The government plans and programs for the future aim to accelerate the structural adjustment of the economy in Shanghai (Shanghai Municipal Government, 2006a,b). This means that the share of the tertiary sector, especially the service sector, will increase while that of industry and construction will decrease, as shown in Table 1.

The industrial sector in Shanghai has been dominated by heavy industry for a long time. The energy consumption by industry is 60% of the total energy consumption, among which sectors like steel and heavy-chemistry contribute 50% of the total industrial energy consumption. The BP scenario assumes that economic structural adjustment in the industrial sector will occur, and it optimizes this adjustment to realize targets of low energy consumption and low pollutant emissions (Shanghai Municipal Government, 2007a,b,c). The intended measures include: (1) phasing out the old technology with high energy consumption, high pollution emissions and low efficiency, (2) developing advanced manufacturing industries with low energy consumption and low pollution emissions, and (3) strengthening the optimization of industrial locations and resource efficiency to reduce energy consumption.

If the shift of industrial structure is implemented as envisioned in the government plans, we estimate the share of the energy-intensive sector would be reduced from 26.63% in 2006 to 18.00% in 2020. The share of manufacturing will increase from 14.74% in 2006 to 24.00% in 2020, as shown in Table 1.

2.3.2.4. Energy structure. The 11th Five-Year Plan for Energy Development in Shanghai (Shanghai Municipal Government, 2007b) indicates that the development of new and renewable energy will be one of the key goals of energy planning. It envisions that the share of renewable energy will reach 0.5% by 2010. The renewable energy in this plan mainly includes wind and solar energy. Wind power in Shanghai is located on three islands and in two districts (Chongming island, Changxing island, Hengsha island, the Nanhui district and the Fengxian district). The plan also calls for solar integrated building construction, demonstration projects for biogas power generation, and improved urban waste disposal.

Shanghai will increase the supply of natural gas and electricity imported from other regions, as well as its share of renewable energy. The plan reduces the share of coal in primary energy consumption from 53% in 2005 to 46% in 2010.

A clean energy plan such as this, aims to accelerate the exploitation and use of both wind and solar energy. By 2010, wind-driven energy generation units will reach 200–300 MW, and solar photovoltaic generation will reach 10 MW.

2.3.2.5. Energy intensity. The 11th Five-Year Plan for Energy Development in Shanghai (Shanghai Municipal Government, 2006a,b) aims to decrease the energy intensity of economic activities in 2010 by 20%, from that of 2005; this means a reduction from 0.88 to 0.70 tce/10,000 Yuan. From 2006 to 2010, the energy intensity of the industrial sector is required to decrease by 35%, the tertiary sector by 15% and energy in buildings by 15%. Under this scenario, the energy intensity of Shanghai in future years is shown in Table 2.

Table 1
Economic structure in future years under the BP scenario.

	2005	2010	2015	2020
GDP, 100 million RMB	9154.18	15614.68	22,943.09	30703.03
Share of primary industry (%)	0.98	0.80	0.70	0.60
Share of secondary industry (%)	48.59	44.20	39.30	34.40
Share of tertiary industry (%)	50.42	55.00	60.00	65.00
Share of high energy intensity sectors in industry (%)	28.19	24.00	21.00	18.00
Share of light industry in industry (%)	57.22	59.00	58.50	58.00
Share of manufacturing in industry (%)	14.59	17.00	20.50	24.00

Table 2
Energy intensity in future years under the BP scenario, units: tce/10k Yuan.

	2006	2010	2015	2020
Primary industry	0.951	0.747	0.662	0.684
Secondary industry	0.883	0.671	0.546	0.515
Tertiary industry	0.471	0.381	0.350	0.374
City average	0.873	0.704	0.568	0.547

2.4. CO_2 emissions projections

For this study, the energy demand and CO_2 emissions up to the year 2020 in Shanghai were estimated according to the framework described in Fig. 1. In this framework, the driving forces of CO_2 emissions are population, economic growth and structure, industrial structure and technological activity, as explained in the scenario descriptions. For projections, a number of steps have been followed. Firstly, the future transitions of the driving forces for each scenario were analyzed. Secondly, the energy demands in various sectors were calculated based on the growth of Shanghai's GDP and the energy intensities of sectors. Thirdly, the energy demands were distributed into the fuel types according to the changes in the energy structure defined by the scenarios. Fourthly, the primary energy demand was calculated based on the efficiency of energy processing and conversion. Finally, the projected CO_2 emissions were estimated based on the energy demand and the carbon emission factors.

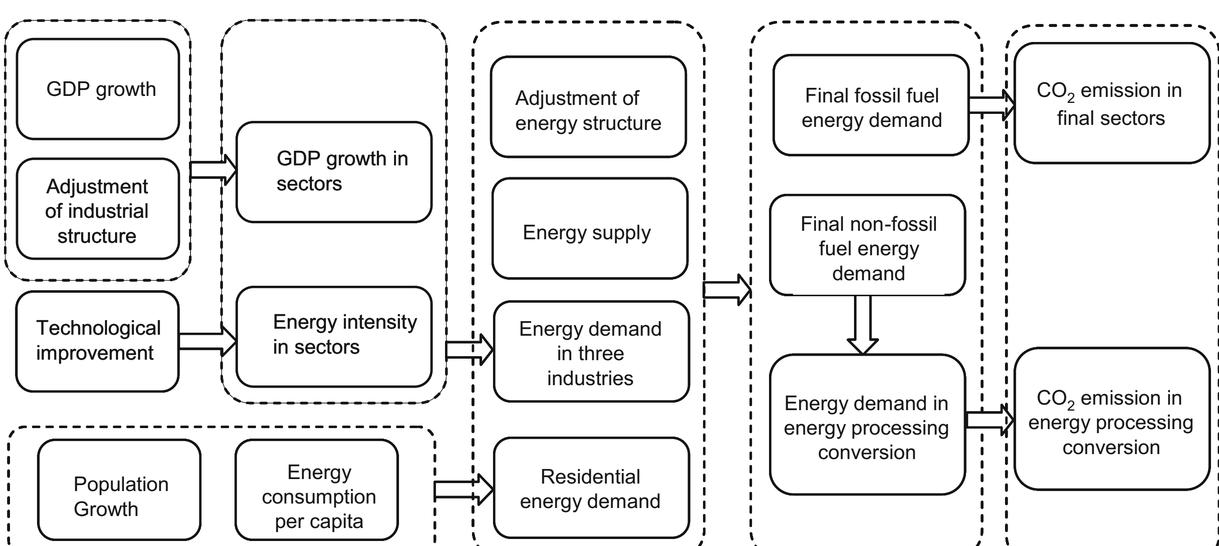

Fig. 1. Schematic framework for projections of energy demand and CO_2 emissions.

3. Results

3.1. Energy consumption in Shanghai

The analysis shows that the total energy consumption in Shanghai has been increasing rapidly from 1995 to 2006. From 1995 to 2006, the total energy consumption increased by 88.3%, which means it rose from 44.79 million tce in 1995, to 84.35 million tce in 2006. In 2006, the share of the final energy consumption was 1.2%, 58.6%, 32.6% and 7.6% for the agriculture, industry (including industry and construction), tertiary (business, service and transport) and residential sectors, respectively, as shown in Fig. 2. The contribution to the GDP from the industrial sector was less than 50%, while it consumed 60% of the final energy consumption due to the fact that the energy intensity of the industrial sector is higher than that of the tertiary sector. In per capita terms, the energy consumption increased from 3.05 to 4.60 tce from 1995 to 2006, which represents an increase of 51%, as shown in Fig. 3. However, due to improvements in technology, the energy intensity decreased from 1.48 to 0.82 tce from 1995 to 2006, representing an annual rate of decrease of 3.7%.

3.1.1. Consumption of primary energy by energy types

Fig. 4 shows the consumption of various energy types in Shanghai during 1995–2006. All of the hard coal is imported from other provinces. The coal is mainly used in heat, power generation and industrial boilers. Coal consumption in 2006 in Shanghai was 30.17 million tce, of which 75% was used for heat and power generation, with the remainder used in industrial boilers. The high share of direct coal burning in end-use sectors not only contributes to the air pollution and CO_2 emissions within Shanghai, but also puts more pressure on the energy supply. Washed coal is mainly used for producing coke and coal gas in Shanghai. The consumption of washed coal in 2006 was 10.92 million tce, of which hardly any is used (one percent) in end-use sectors. The growth in crude oil consumption has been phenomenal; it was 88% higher in 2006 than in 1995 (18.30 million tons in 2006). The crude oil is used to produce other oil products, except for a nominal amount used for non-energy products. Shanghai started to use natural gas in 1999, late compared to other cities, such as Chongqing. Gas consumption has increased significantly since this time, but natural gas still provides only a small share of the total energy consumption. Natural gas consumption reached 2.52 billion m^3 in 2006 in Shanghai, of which 66% was used in end-use sectors and the rest was used in energy processing and conversion. In recent years, the energy structure has become more diversified in Shanghai; the coal share has decreased from 68% in 1995 to 52% in 2006, and the share of natural gas has increased from 0% to 3.8% in 2006, as shown in Fig. 5.

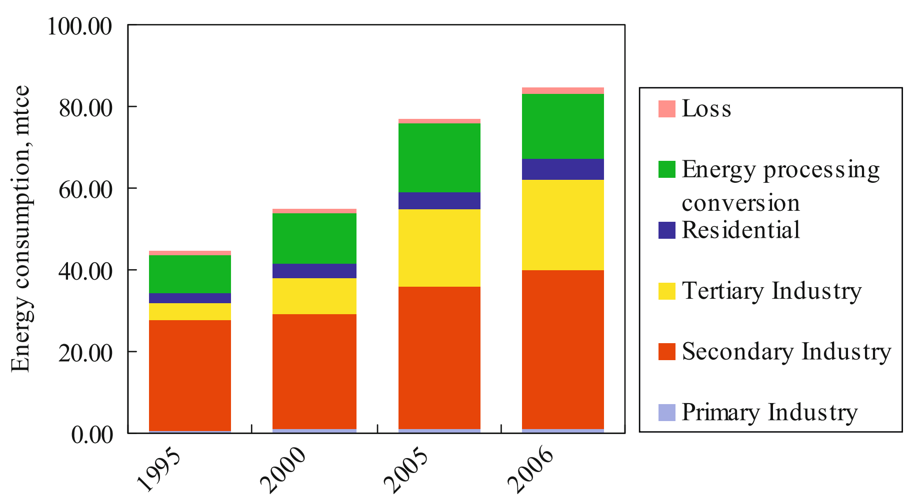

Fig. 2. Change in energy use in Shanghai, 1995–2006.

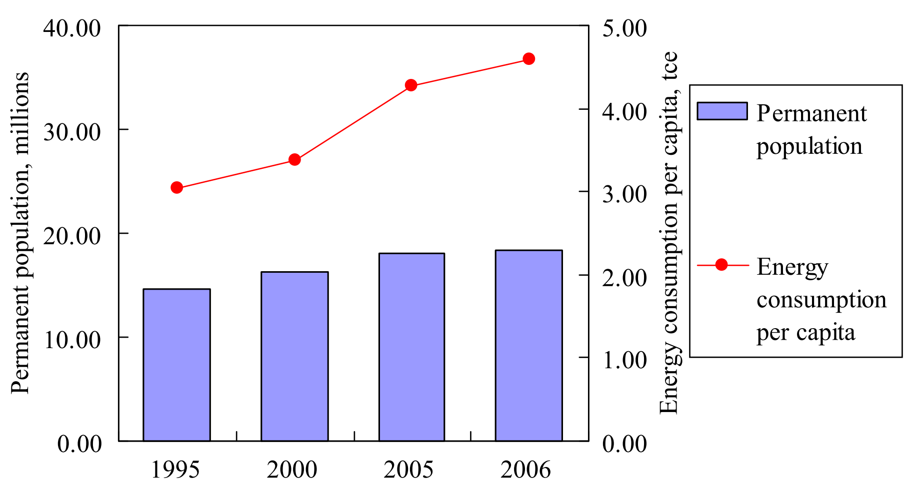

Fig. 3. Change in population and per capita energy use.

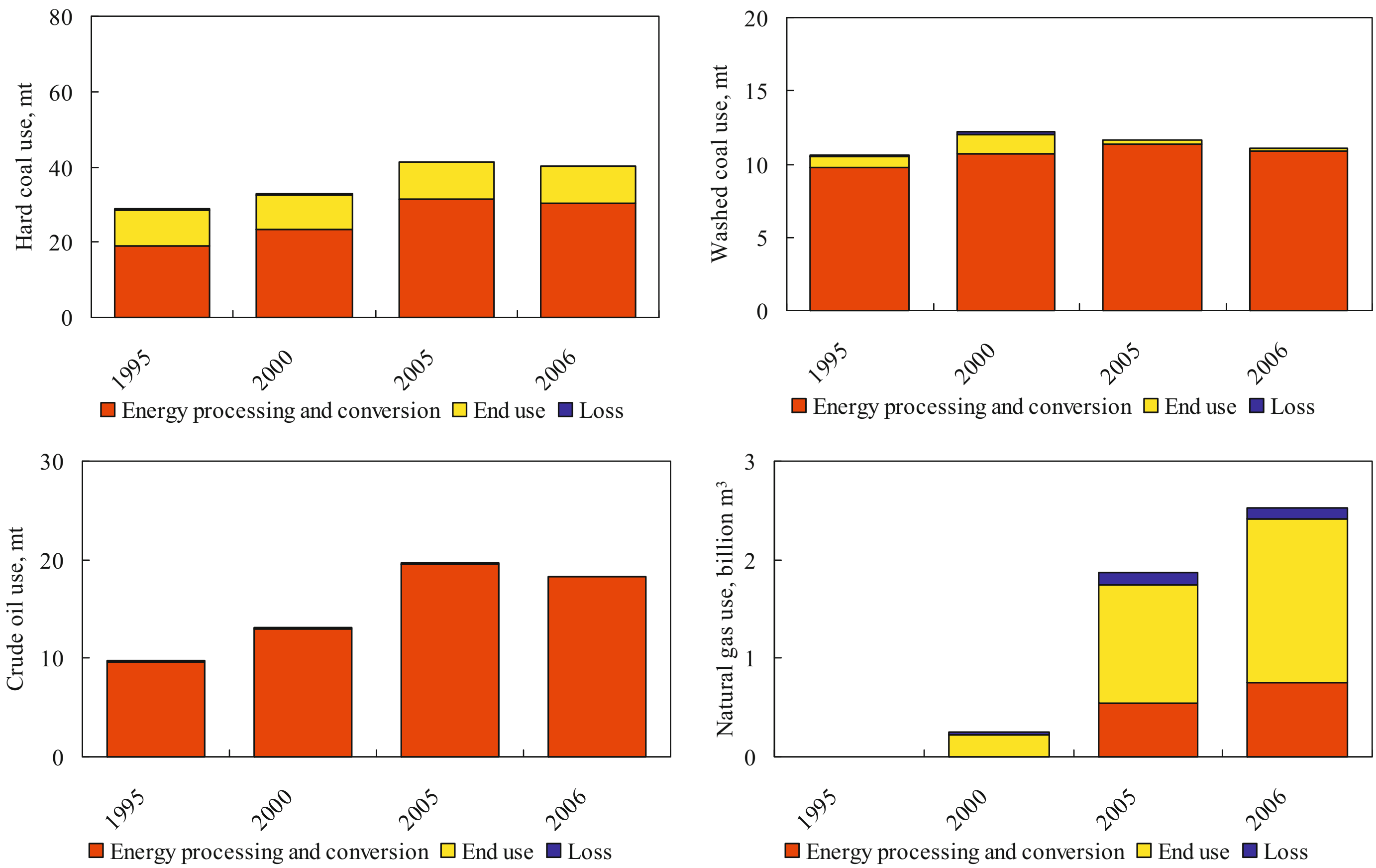

Fig. 4. Consumption of primary energy in Shanghai.

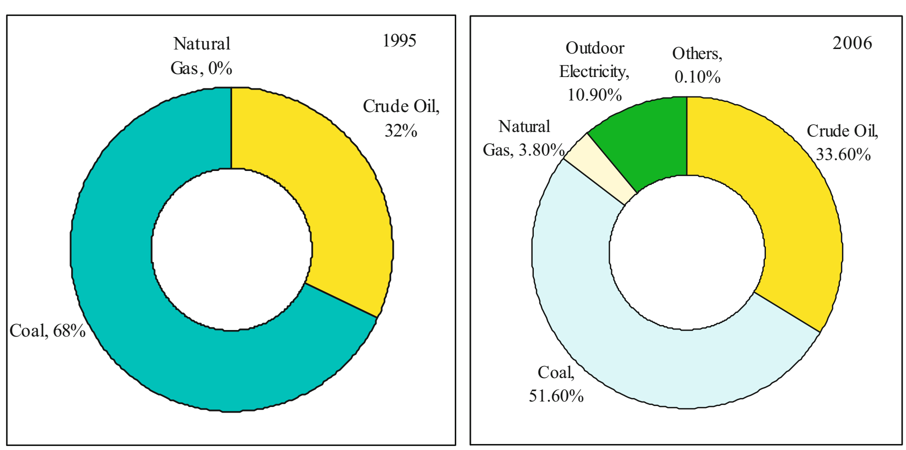

Fig. 5. Adjustment of energy structure in Shanghai.

3.2. CO_2 emissions in Shanghai

3.2.1. Total and sectoral CO_2 emissions

With the rapid rise of energy consumption, the total emissions of CO_2 from energy consumption in Shanghai have increased from 110 million tons in 1995 to 180 million tons in 2006, with an average annual growth rate of 5.7%. As shown in Fig. 6, CO_2 emissions from the end-use sectors were 63.75 million tons in 1995, which was 59.6% of the total. This value increased to 104.5 million tons, 58% of the total in 2006.

In Shanghai, the CO_2 emissions from non-energy activities have also continued to rise with the increase of industrial production. In 1995, CO_2 emissions from the production of cement and glass and the desulfurization process were 1.8 million tons; this reached 33.6 million tons in 2006. Among the non-energy use sector emissions, cement production contributes the largest share of CO_2 emissions, at 93.5% in 2006. Cement production has risen quickly in the past few years due to rapid infrastructure development in Shanghai. Among all of the sectors, energy processing and conversion contribute the largest CO_2 emissions in Shanghai (around 40%). With the continuous adjustment of the industrial structure, the share of CO_2 emissions from the industrial sector gradually decreased from 47% in 1995 to 30% in 2006. In contrast, the vehicle stock (number of vehicles, including four-wheel motor vehicles, motorcycles and mopeds) in Shanghai has increased greatly in the past few years, from 0.43 million in

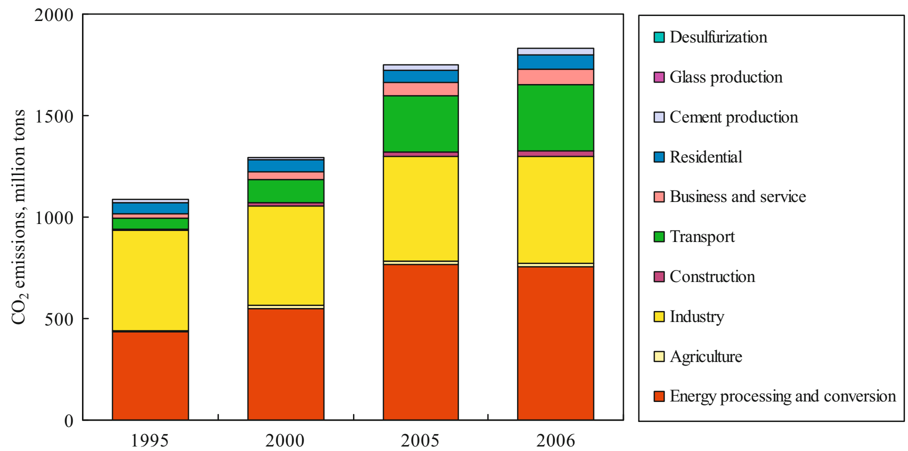

Fig. 6. CO_2 emissions from Shanghai, 1995–2006.

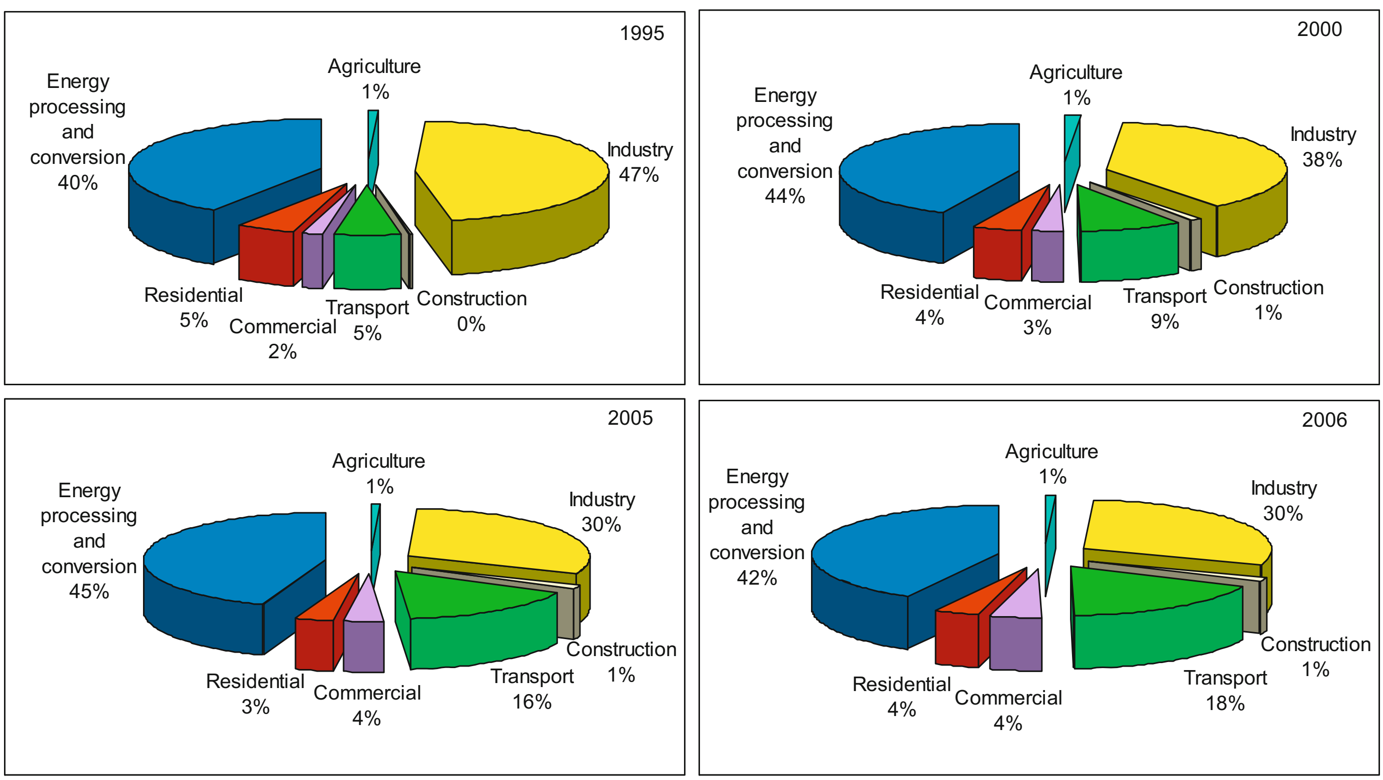

Fig. 7. Share of CO_2 emissions from various sectors in Shanghai, 1995–2006.

1995 to 2.1 million in 2006. Therefore, the CO_2 emissions from the transport sector increased from 7% in 1995 to 18% in 2006, as shown in Fig. 7. The detailed breakdown of energy consumption and the related CO_2 emissions for Shanghai in 2006 are shown in Table 3.

3.2.2. CO_2 emissions from fuel types

Coal is the major primary energy source, and it is highly carbon intensive. This study shows that the CO_2 emissions from coal burning increased from 84 million tons in 1995 to 110 million tons in 2006 in Shanghai. Oil consumption produced 23 million tons of CO_2 in 1995 and 64 million tons in 2006. Consumption of natural gas produced only 5 million tons of CO_2 in 2006.

In recent years, with the adjustment of the energy structure, the share of CO_2 emissions from coal decreased from 78.8% in 1995 to 61.5% in 2006, but the share of natural gas increased from 0% to 3%, in 2006 (Fig. 8). Since the carbon content of energy types differs (for example the carbon contents of hard coal, crude oil and natural gas are 26.4, 20.0 and 15.3 tC/TJ, respectively) an adjustment in the energy structure will play an important role in CO_2 mitigation.

3.3. Future energy demand and CO_2 emissions in Shanghai

3.3.1. Projection of energy demand

Under the BAU scenario, if Shanghai continues its past trends and no new protection related to energy saving and

Table 3
Energy consumption and CO_2 emissions for final sectors in 2006 in Shanghai.

Sectors		Energy use	Share of energy use	CO_2 emissions	Share of CO_2 emissions
	Units	ktce	%	Kt	%
Agriculture		7.88	1.17	1544.85	1.48
	Iron and steel	128.61	19.14	30350.54	29.05
	Nonferrous metal	3.33	0.50	460.77	0.44
	Construction material industry	14.87	2.21	2686.52	2.57
Industry	Basic chemistry	94.77	14.11	7692.37	7.36
	Petrol chemistry	58.96	8.78	3076.04	2.94
	Papermaking	4.70	0.70	832.90	0.80
	Manufacturing	50.41	7.50	5399.12	5.17
	Processing industry	15.97	2.38	2500.44	2.39
	Others	8.61	1.28	113.40	0.11
Construction		14.24	2.12	2374.67	2.27
Transport		157.35	23.42	32,605.39	31.21
Business and service		61.15	9.10	7725.89	7.39
Residential		50.99	7.59	7120.29	6.81

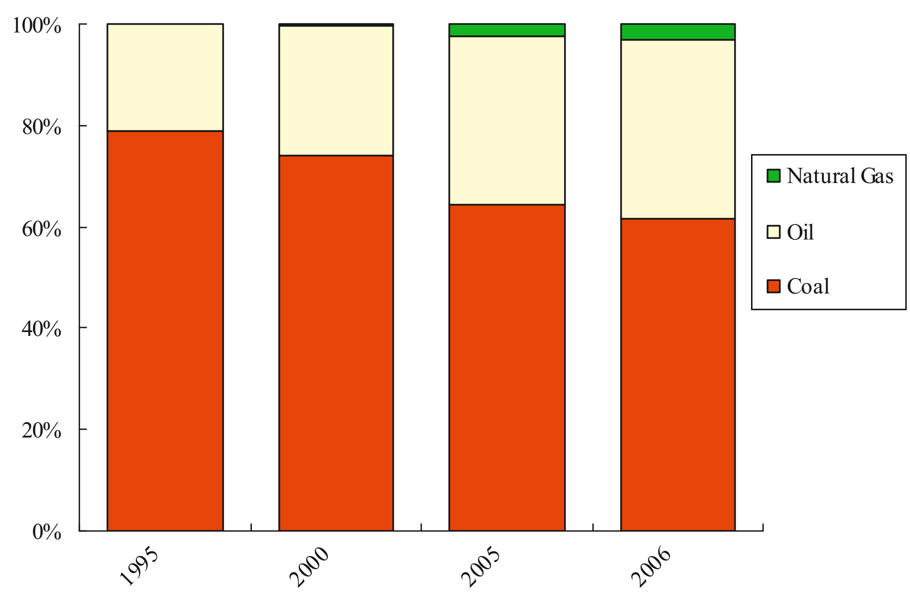

Fig. 8. Share of CO_2 emissions from various energy types in Shanghai, 1995–2006.

environmental protection are implemented, the total energy demand will increase dramatically, reaching 303 million tce in 2020. This is 3.6 times that of 2006, as shown in Table 4. The per capita energy consumption will reach 11.7 tce. This scale of energy demand will put heavy pressure on the energy supply system, local environmental protection and CO_2 emissions reduction targets in Shanghai.

Under the BP scenario, total energy demand in Shanghai will be 158 million tce in 2020, which is twice as large as in 2005, as shown in Table 5. In this scenario, the per capita energy consumption will be 7.7 tce in 2020, which is still far higher than the current national average (3.65 tce, published by China on June 04, 2007).

Table 4
Energy demand under the BAU scenario, units: mtce.

Year	Final energy use	Energy processing conversion	Loss	Total energy demand
2008	88.93	20.14	1.28	110.35
2010	109.93	24.22	1.58	135.72
2015	173.13	35.66	2.47	211.25
2020	251.48	48.48	3.56	303.52

3.3.2. Projections of CO_2 emissions

The total CO_2 emissions in 2006 in Shanghai were 184 million tons. Under the BAU scenario, this will increase to 290 and 630 million tons in 2010 and 2020, respectively, as shown in Fig. 9. Under the BP scenario, CO_2 emissions in 2010 and 2020 will be 210 and 330 million tons, respectively. These amounts are 27% and 49% lower than those of the BAU scenario, as shown in Fig. 9. In per capita terms, this means 24 and 16 t under the BAU and BP scenarios, respectively, in 2020 compared to 10 t in 2006. Under the BAU and BP scenarios, the CO_2 intensities of the economy are 1.62 and 1.07 t per 10,000 Yuan, respectively, in 2020 (in 2005 prices; in 1995 it was 3.53 t per 10,000 Yuan). Compared to the BAU scenario, the BP scenario provides a net reduction in the CO_2 intensity of the economy of 34%.

Table 5
Energy demand under the BP scenario, units: mtce.

Year	Final energy use	Energy processing conversion	Loss	Total energy demand
2008	77.38	17.86	1.13	96.37
2010	80.79	18.03	1.18	99.99
2015	106.93	21.95	1.54	130.43
2020	131.57	24.89	1.88	158.35

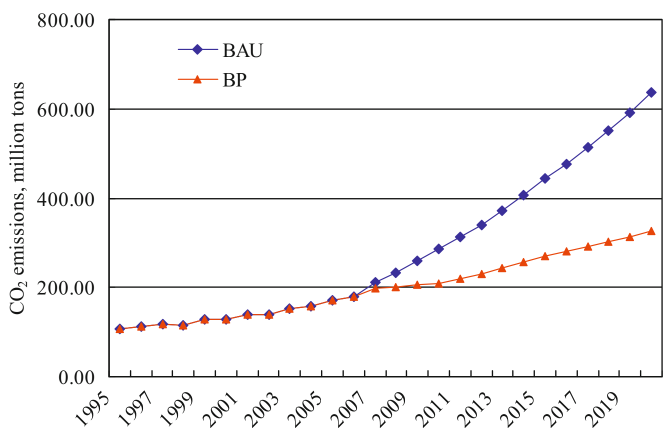

Fig. 9. Trends of CO_2 emissions for two scenarios.

4. Discussions and policy implications

This paper presents the energy and non-energy related CO_2 emissions for 1995–2006, and the projections of energy demand and CO_2 emissions up to 2020 under the BAU and BP scenarios. It also analyzes the CO_2 mitigation potential of the BP scenario that largely reflects the major energy policies of Shanghai. The results of this study highlight several key points that are important for Shanghai.

- The high economic growth rate and associated industrial and urban activities are the major drivers for the tremendous rise in energy use and CO_2 emissions in Shanghai in the past decade, in all sectors. While the share of industry is decreasing due to development of the tertiary sector, the resulting increase from activities such as motor vehicles and buildings shows that people's lifestyles are becoming more energy and carbon intensive. More building construction also demands more cement and glass, and their production increases CO_2 emissions independent of energy use. The consumption aspect of energy consumption poses an additional challenge for Shanghai, in addition to past trends in production and industrial activities.
- Despite some structural shift towards natural gas, the energy system of Shanghai is heavily dominated by coal. Coal is a less efficient form of energy than other clean energy sources. It has a high carbon content and can also cause local air pollution. While there are ways to improve the efficiency of power and heat production, unless carbon capture and storage (CCS) technologies are employed, a significant reduction in CO_2 from the production side alone is very difficult with coal based systems, unless there is an increase in the use of clean fuels and a decrease in energy demands.
- If Shanghai fails to act in relation to energy conservation and CO_2 emission reduction, the future rise in energy use and CO_2 emissions will be huge (3.6 times for energy and 3.4 times for CO_2 in 2020 from 2006). In addition, emissions of air pollutants like SO_2, NO_x, CO, PM_{10}, $PM_{2.5}$ and VOCs in Shanghai will increase by 2.8, 2.8, 2.7, 1.7, 2.3 and 2.5 times, respectively, over those of 2006 (SAES, 2008). Given the large opportunity that exists for improving the energy efficiency of production and consumption activities in Shanghai, opportunities exist to address multiple concerns, such as air pollution, energy security and CO_2 emissions, simultaneously. However, one has to note that reductions in air pollution may not always result in reductions in CO_2 emissions. One such example is that Shanghai has started desulfurization in power plants, which reduces SO_2 emissions, but may increase CO_2 emissions.
- Shanghai has clear plans and policies for energy in place until 2010 that affect CO_2 emissions positively. Improving energy efficiency is one of the top policy agendas of Shanghai, which are explicitly illustrated in the Five-Year Plans (2005–2010) and accompanying sectoral documents of the Shanghai Government. The target of reducing energy intensity by 20% passed down to cities from the national goal requires considerable change in Shanghai. The bases of these plans are economic structural adjustment (more commercial and service sectors), cleaner fuel structure, less reliance on energy-intensive industries and the increase of energy efficiency at all levels. The results from our comparison of the BP scenario with the BAU scenario incorporate some of the key plans and policies and extend them beyond 2010–2020. They reinforce the need for such plans and polices in order to reduce energy consumption and CO_2 emissions in large quantities. Even under our BP scenario, the reductions of energy intensity and carbon intensity in 2020 over 2005 are 37% and 75%, respectively. We do not expect that per capita energy use and CO_2 will decrease from 2005 to 2020 in the BP scenario (per capita CO_2 emissions increased 60% from 2005), due to the fact that Shanghai needs to grow economically and support national economic growth. The best Shanghai can do, perhaps, is dampen the growth of CO_2 emissions. However, globally, cities across the developed world have already published ambitious CO_2 reduction targets (Bangkok, 2007; Dhakal, 2009; Green, 2007; ICLEI 2004; Oxford, 2005; Toronto, 2007; Worcester, 2006). New ambitious global and national emission reduction targets are expected to be agreed upon by the end of 2009. Shanghai, being a prominent city globally, will be under pressure to reduce or dampen its CO_2 growth by a large amount. Our results also show that more CO_2 emissions cutbacks are possible by implementing additional plans and policies beyond those considered in the BP scenario in this study. The BP scenario does not include possible, and likely, plans and policies that are less ambitious. The opportunities are immense.

Economic development and population increase are important drivers of energy consumption and thus CO_2 emissions. Alternate assumptions regarding these two factors can alter results, and this study is no exception. The assumptions regarding population and economic growth in this study are subjective. They were based on Shanghai's related local plans and authors' consultations with other experts, as well as our own judgments. Judging the accuracy of these assumptions is difficult, but we think these assumptions are reasonable and serve the purpose of this paper as long as they are transparent, despite any uncertainties.

Some of the carbon emission factors necessary to follow the IPCC guidelines for making inventories used in this analysis were not available locally from Chinese studies. Thus, we relied on international studies. The emissions factors included in the IPCC guidelines do consider the situation in developing countries, although they may not quite match with the local realities of China. Although, the difference should not be large, this study recommends the development and use of local emission factors for future studies. It is also important to re-state that this study follows the IPCC inventory method, which relies on territorial principal. It does not count CO_2 emissions embodied in electricity imported to Shanghai.

Energy consumption is the major source of CO_2 emissions. However, there are other sources, such as the land use change, that emit CO_2 emissions. Due to the limitation of data and resources, this study only estimates CO_2 emissions from energy use and industrial activities. The authors aim to cover non-energy sectors, non-CO_2 gases, and carbon sinks in Shanghai in future studies.

5. Conclusions

From 1995 to 2006, CO_2 emissions from energy consumption have been increasing rapidly in Shanghai, from 109 to 184 million tons. The emissions from energy conversion and industry contributed the largest shares, followed by transportation, as shown in Fig. 10. In 2006, the CO_2 emissions from energy conversion, industry and transportation contributed 43%, 29% and 18%, respectively, of the total emissions. Shanghai's CO_2 emission per capita in 2006 was 10.02 t per capita (based on total population), which is higher than the world average (4 t per capita) and the national average in China (3.65 t per capita), as shown in Fig. 11.

If Shanghai does not act, the energy demand in 2020 will reach 300 million tce. The CO_2 emissions from energy consumption in 2020 will increase to 640 million tons, from 180 million tons in 2006. This increase will create enormous burden to energy security, environmental protection, CO_2 mitigation and energy conservation.

However, Shanghai already has plans and policies in place until at least 2010, and these plans are reflected in the BP scenario. Under the BP scenario, economic growth will be slow, industrial structure will be further adjusted, the share of tertiary industry will be expanded, high energy consumption sectors will be phased out gradually, modern manufacturing industries will be developed, energy structure will be optimized, the share of coal used for a primary energy source will be reduced and the share of clean energy like natural gas will increase. As a result, the energy demand and CO_2 emissions will be lower than they would be under a do-nothing scenario. In 2020, the total energy demand and CO_2 emissions under the BP scenario will be 48% and 49% lower than those from BAU.

Thus, the current government plans, if completely implemented, will play a major role in reducing energy demand, improving air quality and mitigating CO_2 emissions in Shanghai. If these plans are not implemented fully, then the energy and CO_2 reductions will be less. The CO_2 emissions per capita of Shanghai are larger than those of many cities in developed countries, including Tokyo, London, New York, etc. Given that new climate targets are being discussed globally and many cities have already pledged large CO_2 reductions, Shanghai will come under pressure in the future to either reduce its CO_2 emissions or at least dampen the growth of CO_2 emissions substantially. Our BP scenario considered only planned policies and did not consider likely or potential new policies. However, if currently planned policies are further strengthened, there will be greater potential for reductions in CO_2 emissions from Shanghai. For instance, the share of renewable energies could be increased to be higher than the target of 0.5% in 2010; the share of tertiary industry could be

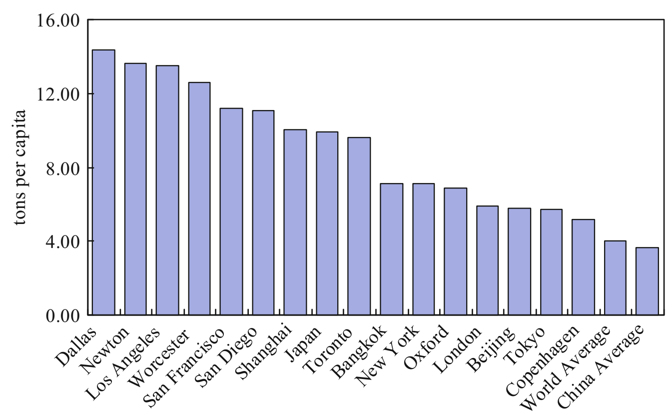

Fig. 11. Comparisons of CO_2 emissions per capita.

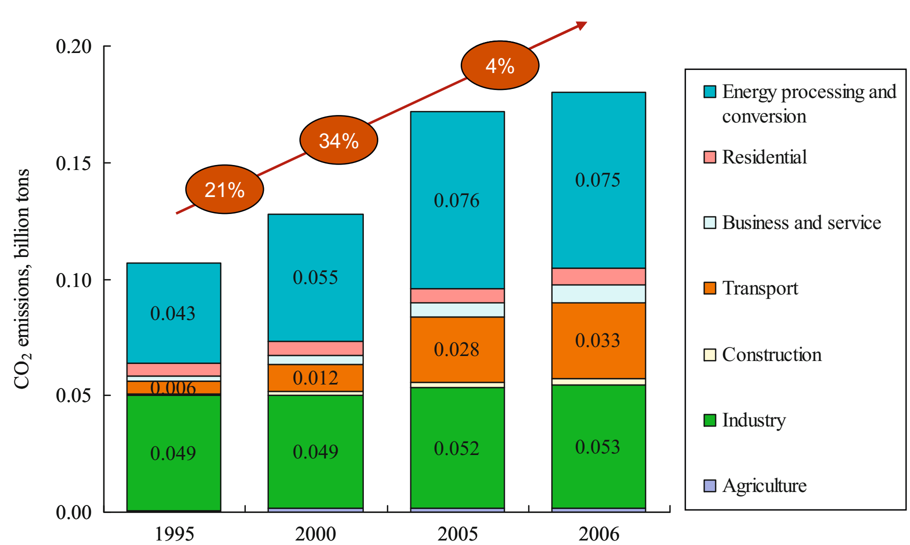

Fig. 10. CO_2 emissions caused by energy consumption in Shanghai, 1995–2006.

increased to more than 65% in 2020, and the phase out of high energy-intensive industries could be accelerated.

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