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ScienceDirect

Energy Procedia 5 (2011) 370–376

Energy Procedia

IACEED2010

Energy Use and CO_2 Emission Inventories in the Four Municipalities of China

Yuhuan Geng[a,b], Changhui Peng[b*], Mingzhong Tian[a],

[a]*School of Earth Sciences and Resources, China University of Geosciences, Beijing, China, 100083*
[b]*Institut des Sciences de L'Environnement, Département des Sciences Biologiques, Université du Québec à Montréal, Montréal, QC, Canada, H3C 3P8*

Abstract

Emission inventories are important tools for monitoring air quality and assisting the policies in urban areas. This paper estimates Beijing, Shanghai, Tianjin, and Chongqing's CO_2 emissions of energy consumption and carbon intensity of the economic activities in 1990, 1995, 2000 and 2004-2007 based on the method recommended by IPCC. The results show that the coal combustion is the leading cause of total CO_2 emission from energy consumption, occupied over 60% of total CO_2 emission of fuels. But the share of CO_2 emission from coal is descending gradually because of energy consumption restructuring. In addition, the four mega-cities' carbon intensity of the economic activities, which is the low Carbon Economy index, is improving persistently. These results imply that China's CO_2 emission in the future may not become as high as expected but improve with time.

Selection and peer-review under responsibility of RIUDS

Keywords: carbon intensity; per capita emissions; uncertainty; urban; suggestion; Beijing; Shanghai;

1. Introductions

Global warming has become the urgent international concern. The Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment has concluded that there is over 90% probability that the global warming is primarily caused by human activities – especially by the fossil fuel combustion [1]. Total greenhouse gas emission has grown exponentially at about 2% per year since 1800, while fossil fuel emissions have accelerated since 2000 to grow at about 3.4% per year. Total CO_2 emission is responsible

* Corresponding author. Tel.: +1-514-987-3000 ext 1056; fax: +1-514-987-4718.
E-mail address: peng.changhui@uqam.ca

doi:10.1016/j.egypro.2011.03.063

for 2/3 of the growth of all GHG emission [2]. Many government and organizations are seeking measures to slow down global warming.

With the development of urbanization in the worldwide, the urban areas are recognized as a major driver of global greenhouse gas emission [3].Over 50% of the world's population is now concentrated in urban areas, consuming 75% of the world's energy and emitting 80% of the total GHG emission [3]. Cities must play a significant role in reducing GHG emissions and tackling global climate changes. In recent years, a number of cities have established GHG emission inventories, which can helps the government to establish and implement the plan, propose pragmatic, and effective measures and schemes to reduce GHG emissions [4-8] .

China's urbanization rate is fast and had been over 40% by 2005 [9]. Huge amounts of energy are consumed and emit massive amount of CO_2. It is urgent to reduce China's urban CO_2 emission. To establish CO_2 emission inventories is a good way to know the CO_2 emission situation. This paper estimates CO_2 emission inventories of 1990, 1995, 2000, and 2004-2007 attributing to the energy consuming department in Beijing, Shanghai, Tianjin, and Chongqing (China's four municipalities). Particularly, the carbon intensities of the economic activities are also calculated. At last, CO_2 emission inventories by fuels and carbon intensity are evaluated and analyzed in detail by fuel type and economic factors.

2. Study Areas, Methodology and Data

2.1 Study Areas

In this paper, we chose China's four municipalities, Beijing, Shanghai, Tianjin, and Chongqing as our study objects. The four mega-cities were selected because they have experienced the highest rate of economical development in China since 1978, and are the most important political, economic, and cultural centres with populations over 10 million. Beijing, Shanghai, and Tianjin have been municipalities for many decades and are highly urbanized, whereas Chongqing was a part of Sichuan Province until early 1997, and is now the largest municipal government.

2.2 Methodology of CO_2 Emission Inventories

We used mass balance approach to estimation CO_2 emissions from energy consumption. Thus, a quantitative analysis is applied to evaluate the resource materials used in the industrial processes: such as industrial production, manufacturing, processing, power supply, heating and road transport, based on the Law of Conservation of Mass. It is calculated using Eq. (1), as follows:

$$E = \sum_i \sum_j Aij \times NCV \times Cij \times Oij \times 44/12 \tag{1}$$

where E is the total CO_2 emission from energy consumption (ton); Aij is the amount of fuel consumption j in sector i (tons or million m^3 for natural gas); NCV is the net calorific value (KJ/(kcal×kg)); Cij is the carbon emission factor of fuel j in sector i (Kg/GJ); and Oij is the carbon oxidation rate of fuel j in sector i. The fuels considered in this paper include the fuel categories used in the energy balance tables: raw coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel, and natural gas [10-11].

2.3 Data Sources

Energy consumption data of each city in 1990, 1995, 2000, and 2004-2007 are derived from *China Energy Statistic Yearbook* 2008; the net calorific values of each fuel are also taken from *China Energy*

Statistic Yearbook 2008; and carbon emission factors are from 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*; the annual GDP data and resident populations are from *China Statistics Yearbook* 1991, 1996, 2001, and 2005-2008. Energy statistics for the earlier years are available at 5-year intervals from 1990 to 2000 and available thereafter for each year from 2004 to 2007. The carbon oxidation rate for the different fuels (O) is taken as the default value of 1, according to the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories*.

3. Results and Discussion

3.1 Estimation of CO_2 Emission Inventories

According to Eq. (4) of mass balance approach, this paper calculated four municipality's CO_2 emission inventories in 1990, 1995, 2000, and 2004-2007 shown in Table 1.

Table 1 CO_2 emission inventories of Beijing, Tianjin, Shanghai, and Chongqing (Unit: 10 000 ton)

	1990		1995		2000		2004		2005		2006		2007	
	E	%	E	%	E	%	E	%	E	%	E	%	E	%
Beijing														
Coal	9915	70.85	11061	69.10	11176	67.80	12076	65.23	12610	66.03	12557	64.75	12265	61.18
Coke	780	5.58	1688	10.55	1514	9.19	1537	8.30	1340	7.02	1175	6.06	1208	6.03
Crude oil	2088	14.92	2007	12.54	2314	14.04	2481	13.40	2451	12.84	2441	12.59	2915	14.54
Fuel oil	739	5.28	634	3.96	289	1.76	216	1.17	213	1.12	155	0.80	138	0.69
Gasoline	175	1.25	233	1.46	330	2.00	614	3.32	728	3.81	861	4.44	1005	5.02
Kerosene	129	0.93	197	1.24	353	2.14	549	2.97	569	2.98	702	3.62	832	4.15
Diesel	147	1.05	157	0.98	248	1.51	404	2.19	431	2.26	544	2.81	588	2.94
Natural gas	19	0.14	27	0.17	255	1.55	633	3.42	751	3.94	953	4.92	1094	5.46
Total	13994		16008		16484		18514		19097		19392		20049	
Shanghai														
Coal	11267	65.27	16206	68.88	18474	66.70	21138	63.27	21879	61.83	21133	60.52	21612	60.30
Coke	1527	8.85	2416	10.27	2428	8.77	1992	5.96	2126	6.01	2210	6.33	2461	6.87
Crude oil	2539	14.71	2993	12.72	4016	14.50	5649	16.91	6031	17.05	5620	16.09	5273	14.71
Fuel oil	1404	8.14	1179	5.01	1598	5.77	2128	6.37	2477	7.00	2606	7.46	2745	7.66
Gasoline	154	0.90	244	1.04	412	1.49	684	2.05	750	2.12	832	2.38	928	2.59
Kerosene	61	0.36	112	0.48	167	0.60	505	1.51	671	1.90	787	2.25	887	2.48
Diesel	305	1.77	376	1.60	541	1.95	1062	3.18	1010	2.86	1137	3.26	1279	3.57
Natural gas					59	0.22	250	0.75	439	1.24	592	1.70	651	1.82
Total	17261		23528		27699		33412		35387		34921		35838	
Tianjin														
Coal	7347	72.08	9977	76.63	10160	71.47	14417	73.52	15620	73.98	15652	70.98	16135	69.49
Coke	462	4.54	504	3.87	484	3.41	1106	5.64	1112	5.27	1825	8.28	2252	9.70
Crude oil	1241	12.18	1497	11.50	2176	15.31	2412	12.30	2646	12.53	2761	12.52	2913	12.55
Fuel oil	737	7.23	503	3.87	257	1.81	368	1.88	364	1.73	346	1.57	289	1.25
Gasoline	114	1.13	231	1.78	348	2.45	367	1.87	368	1.74	395	1.80	434	1.87
Kerosene	5	0.06	11	0.09	56	0.40	45	0.23	45	0.22	49	0.22	58	0.25
Diesel	226	2.22	201	1.54	605	4.26	693	3.53	745	3.53	757	3.44	799	3.44
Natural gas	57	0.56	92	0.71	126	0.89	200	1.02	212	1.00	263	1.19	334	1.44
Total	10192		13019		14216		19610		21115		22051		23218	
Chongqing														

Coal	12089	86.94	11934	84.63	13704	82.08	15345	83.76	16759	83.95
Coke	609	4.38	645	4.58	1308	7.84	1110	6.06	1090	5.46
Crude oil			1	0.01	8	0.05	9	0.05	0	0.00
Fuel oil	8	0.06	13	0.10	11.68	0.07	8	0.05	25	0.13
Gasoline	203	1.46	236	1.68	240	1.44	267	1.46	267	1.34
Kerosene	25	0.18	37	0.27	36	0.22	69	0.38	81	0.41
Diesel	188	1.35	519	3.69	552	3.31	572	3.12	717	3.60
Natural gas	780	5.61	711	5.05%	832	4.99%	939	5.13%	1021	5.11%
Total	13904		14101		16696.37		18322		19964	

3.2 Distribution of CO_2 Emission Inventories

CO_2 emission inventories by fuel type for years 1990, 1995, 2000, and 2004-2007 are shown in Table 1 and Figure 1, where we have also included percentages. In general, CO_2 emission inventories of each municipality have grown fast during the last period. Coal combustion was the leading contributor of total CO_2 emission, as coal had dominated China's energy consumption mix. However, during the past two decades, coal combustion accounted for over 60% of the total CO_2 emission in Beijing, Shanghai and Tianjin, and over 80% in Chongqing. Note that although the total amount of CO_2 emissions from coal use increased, the share of the total CO_2 emission from coal dropped from 1990 to 2007 due to energy restructuring. Besides, CO_2 emissions caused by natural gas and its share in the four cities increased. This switch indicates that energy consumption restructuring in certain cities—from coal dominance to greater share of clean energy such as natural gas, hydropower, and solar—is effective to control CO_2 emissions.

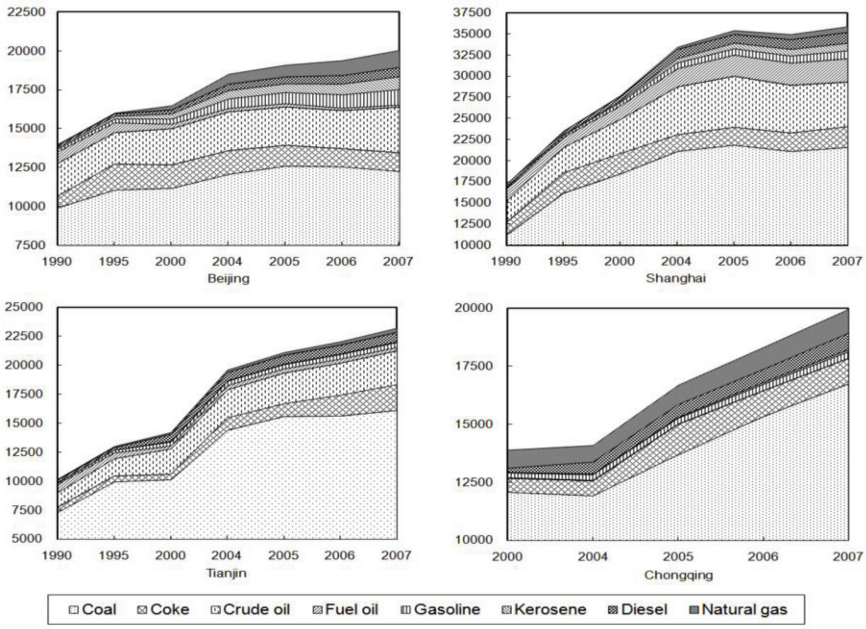

Figure 1 CO_2 Emissions by fuels in Beijing, Shanghai, Tianjin, and Chongqing (Unit: 10 000ton)

In addition, coke consumed in industry emitted a substantial portion carbon dioxide which hasn't changed a lot. Therefore, CO_2 emissions from coke need special attention. Notably, CO_2 emissions caused by diesel and gasoline, and their shares were steadily going up. This was in close agreement with the situation of transport in sectoral emission inventories.

Except for the general characteristics of CO_2 emission, there is remarkable unevenness among the four municipalities. Shanghai had the highest CO_2 emission. From 2004 to 2007, Shanghai held the lead as the biggest CO_2 emitter. In 2007 Shanghai' CO_2 emission reached 35838.66 KT, whereas Beijing, Tianjin, and Chongqing's were 20049.93 KT, 23218.22 KT, and 19964.41 KT, respectively. It is mainly because of the much higher thermal electric capacity installed and accordingly larger amount of coal use in thermal power plants in Shanghai [12]. Furthermore, clear differences are seen in the temporal change of CO_2 emission inventories during the last two decades. As is shown from Figure 1, CO_2 emissions had increased more slowly in Beijing and Chongqing than in Shanghai and Tianjin. CO_2 emissions increased by 64.39% and 78.41% in Beijing and Chongqing versus 145.91% and 137.04% in Tianjin and Shanghai. This was because Shanghai and Tianjin already contained a large number of industrial plants and recently introduced many new ones.

3.3 Distribution of CO_2 Emissions by GDP and per Capita

Generally speaking, the urban development is accompanied with CO_2 emissions. Economic development and dense population usually need much more fuel energy, directly producing huge CO_2 emissions. In this study, CO_2 emissions by GDP and per capita are calculated as key indicators of the extent to which the economy and population depend on energy. Table 2 and Figure 2 present the historical CO_2 intensities and per capita CO_2 emissions for the municipalities.

Table 2 CO_2 emissions by GDP and per capita of the four municipalities

Year	1990	1995	2000	2004	2005	2006	2007	Unit
Beijing								
CO_2 emissions by GDP	27.94	11.48	6.65	3.06	2.77	2.47	2.14	ton/10000Yuan
CO_2 emissions per capita	12.95	12.80	11.93	12.40	12.42	12.27	12.28	ton/capita
Shanghai								
CO_2 emissions by GDP	22.82	9.55	6.09	4.14	3.86	3.37	2.94	ton/10000Yuan
CO_2 emissions per capita	12.91	16.63	16.55	19.18	19.90	19.24	19.29	ton/capita
Tianjin								
CO_2 emissions by GDP	32.78	14.15	8.67	6.30	5.71	5.08	4.60	ton/10000Yuan
CO_2 emissions per capita	11.57	13.82	14.20	19.15	20.25	20.51	20.82	ton/capita
Chongqing								
CO_2 emissions by GDP			8.75	5.24	5.44	5.31	4.84	ton/10000Yuan
CO_2 emissions per capita			4.50	4.52	5.97	6.53	7.09	ton/capita

(2009 average foreign exchange rate, 1US$=6.832 Yuan) (Beijing Statistics Bureau)

No significant differences in CO_2 intensity were observed across our study. The overall trend for each city decreased sharply before 2004 and declined slowly after 2004. This is attributable to the close relationship between CO_2 emissions and GDP in each city.

In addition, CO_2 emissions per capita for Beijing, Shanghai, and Tianjin were about 12 tons/capita each in 1990. However, these indicators had doubled in Shanghai and Tianjin by 2007, whereas they remained stable in Beijing. This was because that Beijing's Olympic Games provided a powerful motivation for environmental improvement in Beijing. Chongqing's CO_2 emissions per capita were much lower than the other three cities, increasing from 4.50 tons/capita in 2000 to 7.09 tons/capita in 2007. This was due to the large population in Chongqing: at over 28 million, it was almost twice the population of other municipalities.

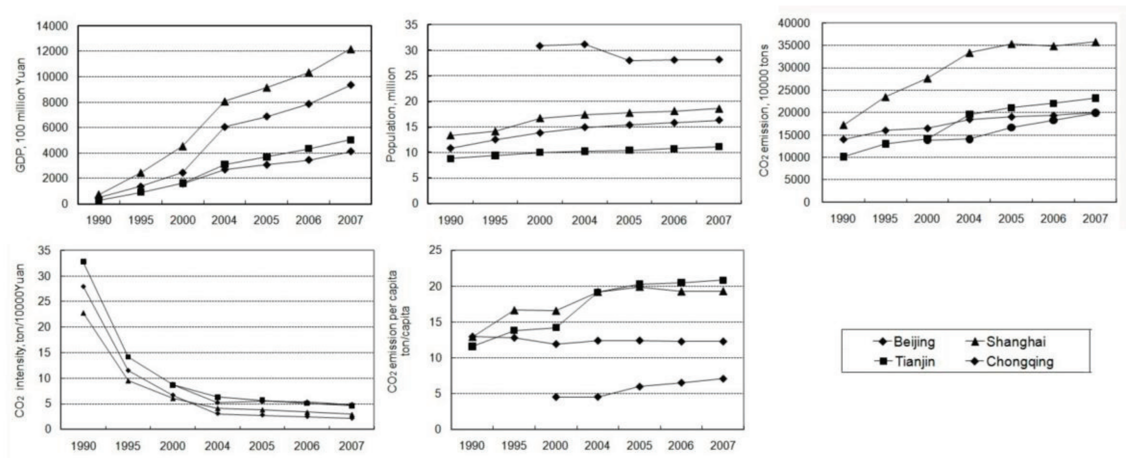

Figure 2 Total CO_2 emission, GDP, population, CO_2 intensity, and CO_2 emissions per capita of the four municipalities

3.4 Suggestions

China is currently undergoing rapid industrialization and urbanization. Urban CO_2 emissions have increased tremendously due to increased energy consumption. As the biggest developing country, the China has set its priority on developing its economy and eliminating poverty now and in future. At the same time, emissions reduction also needs pursuing. CO_2 emissions have placed hard restrict for the economic development. For China, CO_2 intensity is the important indicator to measure the emissions level.

The positive function of our inventory is for government to learn about the emission inventories of energy consumption and make better low carbon eco-city development strategies. It requires the government to increase energy consumption efficiency and use more and more clean energy, to establish related laws, statutes, the management institutions and mechanisms, and to enhance public awareness of energy saving and GHG mitigation [13]. Industries, corporations and plants with high energy consumption, and high pollution and emissions must be reformed [14]. As the four municipalities of China, Beijing, Shanghai, Tianjin, and Chongqing should pay much attention to CO_2 emission reduction and lead a positive way for the other cities in China. At present, CO_2 emissions by energy in the four cities are dominated by coal combustion, but the coal consumption is decreasing gradually. More and more energy demand will be filled by clean energy instead of coal, such as hydropower, nuclear, solar, wind, etc., and thus coal's predominant position in energy consumption will be replaced quickly [12]. With the replacement of more and cleaner energy consumption, there will be a decline in CO_2 emissions, and a growth in the GDP and digressive carbon intensity will be achieved.

4. Conclusions

Emission inventories are an important tool to monitor the changes in the emissions situation and to indicate if improvement measures are effective or not. But current emission inventories in China are very less. Our research provides basic CO_2 emission inventories for local government to make better energy policies and improve energy structure. Meanwhile, our result shows that the carbon intensity of the economic activities is decreasing fast. Therefore, it can be expected that future CO_2 emissions may not become as high as previously expected. So China's target of decreasing carbon intensity by 40-45% between 2005 and 2020 is not a sugar-coat or anguish-free. With the energy restructuring, the promise will be realized. As the next step, future research could assess potential CO_2 emission reduction methods.

The research on CO_2 emissions should also be extended to cover all sources, including land use, traffic, waste, etc. Furthermore, the previous research focus on CO_2 should also be broadened in biogeochemical and physical aspects as a good tool to mitigate climate change.

Acknowledge:

This article was funded by the China Scholarship Council (CSC) and the Natural Science and Engineering Research Council (NSERC) Discovery Grants.

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