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Measuring the Interprovincial CO_2 Emissions Considering Electric Power Dispatching in China: From Production and Consumption Perspectives

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Abstract: How to accurately measure the interprovincial CO_2 emissions is key to achieving the task of energy saving and emission reduction. Electric power is very important for economy development. At the same time, the amount of interprovincial electric power dispatching is very large in China, so it is obligatory to measure the CO_2 emissions from both electricity production and consumption perspectives. We have measured China's interprovincial CO_2 emissions from fossil fuel combustion during 2000–2014, in which the revised regional electric power CO_2 emissions are used to adjust interprovincial CO_2 emissions. The obtained results show that: no matter from which perspective one considers the situation, the overall CO_2 emissions of China are almost the same amount. From different perspectives, the interprovincial CO_2 emissions are different. In terms of the production perspective, CO_2 emissions of Beijing, Hebei, Shandong, Shanghai, Jiangsu, Zhejiang and Guangdong are underestimated. However, Shanxi, Inner Mongolia, Hubei, Sichuan, Guizhou, and Shaanxi are overestimated. If the electric power dispatching is not considered, it is unfairly portrayed as transferring CO_2 emissions from the electricity input provinces to the output ones, because the electricity input provinces enjoy clean energy, but the electricity production ones pay for the environmental pollution.

Keywords: interprovincial CO_2 emission; electric power dispatching; production perspective; consumption perspective

1. Introduction

During the past 30 years, China's economy has experienced a rapid development, while consuming a large amount of energy, which has caused many environmental problems such as smog, sand storm and acid rain. All these problems seriously affect the sustainable economic development of China. It is urgent to solve the dilemma of simultaneously achieving economic development and environmental protection. China, as the biggest energy consumer and CO_2 emitter, clearly indicates in U.S.-China Joint Announcement on Climate Change that China intends to achieve a peak of CO_2 emissions around 2030 [1].

A large amount of research has been done on energy saving and emission reduction. From the perspective of energy efficiency, Zhou *et al.* [2], Yang *et al.* [3], Wang *et al.* [4] and Zhang *et al.* [5] investigated how to save energy and reduce CO_2 emissions by improve energy efficiency. From the perspective of key factors, Wang *et al.* [6] and Li *et al.* [7] tried to find out key factors that affect CO_2 emissions, then put forward corresponding energy saving and emission reducing measures. From the perspective of industry, Lin *et al.* [8], Li *et al.* [9], Mi *et al.* [10], Zhang *et al.* [11] , Xiang *et al.* [12], Xiao *et al.* [13] and Chi *et al.* [14] attempted to find out key industries or enterprises in energy saving and emission reduction. All the researches, although from different perspectives, must be based on the accurate measurement of CO_2 emissions.

The 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories [15] introduces three Tiers and one Reference Approach to measure energy-related CO_2 emissions. Tier 1 method is subject to national fuel combustion data and default emission factors provided by IPCC. Tier 2 method is subject to national fuel combustion data and specific national emission factors. Combustion amount and emission factors of Tier 3 method are both subject to industrial data, which is a departmental method implemented from the bottom up. The accuracy is improved from Tier 1 to Tier 3 but industrial data are usually unavailable. Reference approach is an effective method when there are limited data. The basic idea of this method is to use the activity data multiplied by the emission factors. Current research varies in the selection of activity data, and is characterized as follows:

Firstly, activity data is based on primary energy consumption including coal, oil and natural gas [16–19]. This method is simple and easy to use. However, there will be a relatively big deviation of interprovincial CO_2 emissions when primary energy consumption data is used, because it does not take into account the transfer of CO_2 emissions when secondary energy (electricity, coke, gasoline, diesel and fuel oil, *etc.*) are transferred in and out the provinces. It cannot measure the CO_2 emissions responsibility of each province precisely.

Secondly, activity data is based on various fuel types in the energy balance sheet. Wang and Zhang [20] used the total final consumption data of 15 types of fossil fuel according to the energy balance sheet to measure the CO_2 emissions of all provinces of China. Wang *et al.* [21] used the total final consumption plus input and output of transformation as activity data. However, there are different activity levels of "total primary energy supply", "input and output of transformation", and "total final consumption" in the energy balance sheet. There are great differences in interprovincial CO_2 emissions based on different activity data. Different activity data means different CO_2 emissions responsibilities.

Thirdly, a few studies have considered the issue of CO_2 emissions transfer during the process of secondary energy production, especially in electricity production and dispatching. Because of the complexity of electricity dispatching, only a few researchers consider the interprovincial electricity dispatching in the calculation of CO_2 emissions [22,23]. However, they only use an average electric power emission factor to measure electricity CO_2 emissions of different provinces. They ignore the difference of electric power emission factors in different provinces due to different sources of electricity.

To solve the shortcomings, we can measure the interprovincial CO_2 emissions from both electricity production and consumption perspectives, corresponding to different CO_2 emissions responsibilities. The contributions lie in the following aspects: (i) we measure the interprovincial CO_2 emissions based on the energy balance sheet which can effectively distinguish various types of fuel. This includes not only the primary energy sources of coal, oil, natural gas, but also secondary energy, such as coke, coke oven gas, gasoline, diesel, fuel oil, liquefied petroleum gas *et al.* Provinces should be responsible for the CO_2 emissions produced by their energy consumption. In order to more accurately measure CO_2 emissions of the provinces; (ii) we consider the issue of CO_2 emissions generated in the production process of secondary energy. Production of secondary energy mainly includes thermal power generation, heat supply, coking and oil refining. CO_2 emissions in coking and oil refining mainly occur in consumption process, and CO_2 emissions are relatively small in production process. Therefore, CO_2 emitted in the coking and oil refining is not considered in this paper. In contrast, CO_2 emissions of thermal power generation and heat supply are mainly incurred in the production process. In China, CO_2 emissions of thermal power account for a huge amount of total CO_2 emissions of fossil fuel consumption [24,25]. Electricity input amount in eight provinces of Guangdong, Hebei, Jiangsu, Beijing, Zhejiang, Shanghai, Liaoning and Shandong is more than 550 billion KWh; electricity output amount of Inner Mongolia, Shanxi, Hubei, Guizhou and Anhui is more than 330 billion KWh. In face of such a huge amount of electricity dispatch, if we do not consider the transfer of CO_2 emissions caused by the electricity dispatch, will make the provinces dispatching out electricity to bear more emissions responsibilities than the actual; (iii) most importantly, we try to make the electric power emission factors accord with the actual situation of the provinces. There are no official electricity emission factors in China. Some researches measure electricity CO_2 emissions with reference to "China's regional grid baseline emission factors" determined by the Department of Climate Change of National Development and Reform Commission. However, this emission factor mainly reflects CO_2 emissions of thermal electricity. Electricity consumed by some provinces is a large proportion of hydroelectricity. Proportions of hydroelectricity are relatively high especially in Hubei, Hunan, Chongqing, Sichuan, Guangxi and Yunnan, which are 61.9%, 39.8%, 34.2%, 70.5%, 42.5% and 67.7% respectively. If the electricity consumed in these regions is measured by thermal electricity emission factor, the result will be higher. This paper calculates comprehensive electricity emission factors of regional electric power grid according to regional electricity dispatching feature.

The remainder of this paper is organized as follows. In Section 2, the research methods and data used in this study will be explained in detail. Section 3 provides the discussion and results. Conclusions will be drawn and corresponding policy suggestions proposed in Section 4.

2. Research Methods

2.1. Basic Method

Referring to the Reference Approach of *IPCC2006 Guidelines* [15], we measure energy-related consumption CO_2 emissions:

$$TC = \sum (Q_i \times \delta_i) \tag{1}$$

where TC is the amount of CO_2 emissions produced by energy consumption; Q_i is the consumption of the i^{th} fossil fuel, presented by physical unit (unit: t or m^3); δ_i is the CO_2 emission factor of the i^{th} fossil fuel (unit: tCO_2/t or tCO_2/ m^3); i represents the types of fossil fuel, including raw coal, cleaned coal, other washed coal, coal briquette, coke, coke oven gas, natural gas, liquefied natural gas, crude oil, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas. Fuels of "other petroleum products", "other coked products" and coal gangues that are not mainly used for combustion are excluded. CO_2 emission factors of 12 types of major energy are shown in Table 1.

Table 1. CO_2 emission factors of 12 types of major energy.

Item	CO_2 Emission Factors	Item	CO_2 Emission Factors
raw coal	1.98 t/t	liquefied natural gas	2.84 t/t
cleaned coal	2.49 t/t	crude oil	3.10 t/t
other washed coal	0.79 t/t	gasoline	3.18 t/t
coal briquette	1.72 t/t	kerosene	3.15 t/t
coke	3.02 t/t	diesel	3.18 t/t
coke oven gas	7.42 t/(10^4 m^3)	fuel oil	3.13 t/t
natural gas	21.84 t/(10^4 m^3)	liquefied petroleum gas	2.98 t/t

Note: CO_2 emission factors are calculated by the conversion factor for the fuel to energy units (TJ) on a net calorific value basis in the China Energy Statistical Yearbooks [26] and carbon content referred by IPCC [15].

2.2. Measurement of CO_2 Emissions from the Perspective of Production

From the production perspective, the responsibility of CO_2 emissions is included in fuel combustion places. Therefore, CO_2 emitted in thermal power generation and heat production is included in energy consumption CO_2 emissions of the province that produces them. However, some kinds of energy are used as industrial raw materials and not directly combusted in final consumption. These types energy consumption will not produce CO_2 emissions, so this consumption amount shall be excluded. Moreover, as CO_2 emissions of electricity and heat are already calculated at the production process, they are not included into energy consumption CO_2 emissions to avoid an overlap in calculation. Therefore, provinces should be responsible for the CO_2 emissions produced by their energy consumption.

$$TC_1 = \sum [Q_i\,(\text{total final consumption} + \text{thermal power consumption} + \text{heating consumption}\,) \times \delta_i] \quad (2)$$

where, TC_1 is energy consumption CO_2 emission from the production perspective. Q_i is the consumption of the i^{th} energy, δ_i is the CO_2 emission factor of the i^{th} energy, as shown in Table 1.

2.3. Measurement of CO_2 Emissions from the Perspective of Consumption

From the perspective of consumption, apart from CO_2 emitted in actually consumed energy, CO_2 emitted in the electricity production process is also included in total CO_2 emission of the electricity consumption place. Therefore, from the perspective of consumption, CO_2 emission in the production processes of thermal power generation and heat supply shall be included into total CO_2 emission of electricity and heat consumption places.

At present, concentrated heat supply of a city has regional monopoly in China. One thermal area is often equipped with one thermal source and heat power is seldom dispatched across regions [27]. Therefore, CO_2 emissions of heat consumption can be measured according to energy actually consumed to produce it. CO_2 emission factor of heat does not need to be calculated.

As for electric power emission factors, this is much more complex. "China's regional grid baseline emission factors" determined by Department of Climate Change of National Development and Reform Commission, which we denote by δ_{e1}, as shown in Table 2, only reflects CO_2 emission of thermal electricity. Song *et al.* [22] use "national electricity CO_2 emissions/national electricity generation" as electricity emission factor for input electricity, which neglects the difference of electricity sources of different regions and cannot measure electricity CO_2 emissions of all the provinces effectively. Zhou *et al.* [23] use "provincial CO_2 emission/provincial electricity generation" as the electric power emission factor for electricity input provinces and use "thermal electricity emission factor × thermal electricity proportion" as electric power emission factor for electricity production provinces. They consider emission factors of electricity with different sources but emission factors of input electricity must be the same as that of the output province. However, the fact is the electricity emission factors of production province and consumption province are not the same. Therefore, we calculate comprehensive electricity emission factors of regional electric power grid according to regional electricity dispatching feature. Revised electric power emission factor is calculated as:

$$\delta_{e2} = \frac{Q_i^e \times \delta_i}{E^e} \quad (3)$$

where δ_{e2} is the revised electric power emission factor, Q_i^e is the amount of type i energy consumed to produce electricity in a region. E^e is the amount of electricity produced in a region, including thermal electricity, hydroelectricity and other electric power.

To calculate δ_{e2}, we refer to power grid division made by the Department of Climate Change of National Development and Reform Commission of China. There are six regions: north China (Beijing, Tianjin, Hebei, Shanxi and Inner Mongolia), northeast China (Liaoning, Jilin and Heilongjiang), east China (Shanghai, Jiangsu, Zhejiang, Anhui and Fujian), central China (Henan, Hubei, Hunan, Jiangxi, Sichuan and Chongqing), northwest China (Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang) and south China (Guangdong, Guangxi, Yunnan, Guizhou and Hainan). We use Formula (3) to calculate the revised electric power emission factor of six regions of China, as shown in Table 3.

It can be found by comparing Table 2 with Table 3 that revised electric power emission factor is lower than baseline emission factor of regional power grid of China, especially for central China, northwest China and south China revised electric power emission factor is about 40% lower than baseline emission factor of regional power grid of China. This is because hydroelectricity resources in these regions are abundant.

Table 2. China's regional grid baseline emission factors. Unit: (tCO_2/MWh).

Regions	2003–2005	2004–2006	2005–2007	2006–2008	2007–2009	2008–2010	2009–2011	2010–2012
North	1.1208	1.1169	1.0069	0.9914	0.9803	1.0021	1.0302	1.058
Northeast	1.2404	1.2561	1.1293	1.1109	1.0852	1.0935	1.112	1.1281
East	0.9421	0.954	0.8825	0.8592	0.8367	0.8244	0.81	0.8095
Central	1.2899	1.2783	1.1255	1.0871	1.0297	0.9944	0.9779	0.9724
Northwest	1.1257	1.1225	1.0246	0.9947	1.0001	0.9913	0.972	0.9578
South	1.0119	1.0608	0.9987	0.9762	0.9489	0.9344	0.9223	0.9183

Note: Data on China's regional grid baseline emission factors are from China's clean development mechanism website: http://cdm.ccchina.gov.cn/ [28–36].

Table 3. Revised electric power emission factors. Unit: (tCO_2/MWh).

Regions	2000	2001	2002	2003	2004	2005	2006	2007
North	0.979	0.984	0.970	0.911	0.971	0.984	0.938	0.904
Northeast	0.856	0.922	1.039	1.037	1.082	1.072	1.055	0.995
East	0.965	0.946	0.761	0.979	0.940	0.904	0.894	0.882
Central	0.607	0.597	0.630	0.650	0.719	0.665	0.655	0.637
Northwest	0.754	0.697	0.766	0.762	0.811	0.749	0.752	0.749
South	0.582	0.600	0.587	0.643	0.594	0.690	0.725	0.697
Regions	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	
North	0.903	0.877	0.863	0.915	0.888	0.855	0.793	
Northeast	1.006	0.991	0.959	0.979	0.960	0.908	0.907	
East	0.862	0.822	0.806	0.820	0.830	0.778	0.778	
Central	0.575	0.577	0.589	0.659	0.593	0.623	0.566	
Northwest	0.725	0.718	0.705	0.709	0.696	0.676	0.622	
South	0.585	0.586	0.557	0.543	0.489	0.492	0.399	

Note: Calculation is based on Formula (3) and data from the *China Statistical Yearbook* and the *China Energy Statistical Yearbook* from 2000 to 2015 [26].

In theory we should cite the sources for the electricity inflow and outflow data for each province. However, interprovincial power dispatching is very complex. Limited by data availability, we assume the electricity of the province is for the use of the province's priority. After that, the shortage will be dispatched from other provinces and the excess will be dispatched out of the province. Thus, from the perspective of consumption, CO_2 emissions are measured as:

$$TC_2 = TC_1 + QED \times \delta_{e2} \tag{4}$$

where TC_2 is CO_2 emissions from the perspective of consumption; QED is the amount of dispatched electricity; when electricity is dispatched out, QED is negative and when electricity is dispatched in, QED is positive; δ_{e2} is revised electric power emission factor.

2.4. CO_2 Emission Responsibility

For the purpose of revealing CO_2 emissions responsibilities from different perspectives, production and consumption perspectives, we define:

$$\Delta = TC_1 - TC_2 \tag{5}$$

If $\Delta > 0$, CO_2 emissions responsibility from production perspective are overestimated, it indicates that the energy produced by these provinces is not entirely consumed locally, and they are energy exporting provinces; if $\Delta < 0$, they are underestimated.

2.5. Other Measuring Methods

To compare the difference of actual energy consumption CO_2 emissions measured by different methods, we further select other methods for comparative analysis.

$$TC_3 = \sum [Q_i\,(\text{total final consumption} + \text{heating consumption}\ ) \times \delta_i + QE \times \delta_{e2}] \tag{6}$$

$$TC_4 = \sum [Q_i\,(\text{total final consumption} + \text{heating consumption}\ ) \times \delta_i + QE \times \delta_{e1}] \tag{7}$$

$$TC_5 = \sum [Q_i\,(raw\,coal,\ crude\,oil,\ natrual\ gas) \times \delta_i] \tag{8}$$

where, TC_3 represents total CO_2 emissions when revised electric power emission factors are used to calculate total consumed electricity CO_2 emissions; TC_4 represents total CO_2 emissions when China's regional grid baseline emission factors are used to calculate total consumed electricity CO_2 emissions; TC_5 represents CO_2 emissions measured on the basis of primary energy consumption. QE represents electricity consumption and δ_{e1} represents China's regional grid baseline emission factor.

3. Empirical Analysis

3.1. Data

We chose 30 provinces in mainland China as the sample of our study (excluding Tibet, Taiwan, Hong Kong and Macao). Data on the fossil fuel consumption, including "total final consumption", "thermal power consumption" and "heating consumption" of 12 types of major fossil fuels, of each province is collected from the energy balance sheets of the *China Energy Statistical Yearbook* [26]. Electricity consumption and production data is also from *China Energy Statistical Yearbook* [26].

3.2. Overall National CO_2 Emission Analysis

According to Figure 1, we can find that no matter from which perspectives the situation is considered, the amount of overall CO_2 emissions of China rose from 2000 to 2014 with an annual growth rate of about 9%, from 3.6 billion tons in 2000 to more than 10 billion tons in 2014. Especially from 2000 to 2005, the CO_2 emissions rose rapidly; after 2005, CO_2 the emissions growth rate slowed down but the development trend fluctuated. TC_1 is energy consumption CO_2 emissions from production perspective, and TC_2 is from consumption perspective. From Figure 1 we can see that, the gaps between TC_1 and TC_2 are small, about 0.5%, which indicates national CO_2 emissions measured from the perspectives of production and consumption are approximately the same. Meanwhile, it also indicates the electric power emission factors revised by this paper are reasonable.

Total CO_2 emissions measured by TC_4 and TC_5 are both about 10% higher than by TC_1. The reason is in TC_4 all electricity consumption CO_2 emissions are based on thermal electricity emission factors, no matter it is thermal electricity or hydroelectricity. Thus, national CO_2 emissions will be overestimated. It further proves the revised regional electric power emission factors comply with actual situation better than China's regional grid baseline emission factors when calculate electricity CO_2 emissions. As for TC_5, activity data is based on primary energy consumption. However, some types of energy such as "other petroleum products", "other coked products" and coal gangues produced by the primary energy are not mainly used for combustion, so TC_5 overestimates the national CO_2 emissions.

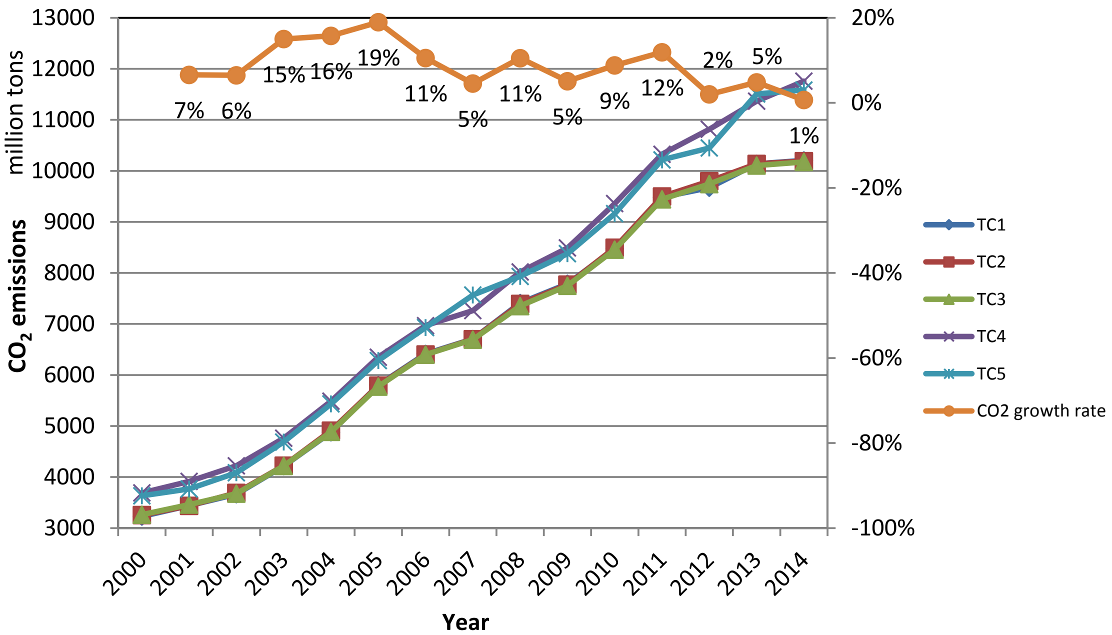

Figure 1. Energy Consumption CO_2 Emissions of China (2000–2014).

3.3. Interprovincial CO_2 Emission Analysis of Different Measuring Methods

We adopt the principle: combination of consumption and responsibility. Therefore, in this part, we take TC_2 as the benchmark, and compare it with other methods. Table 4 comparatively shows difference of interprovincial energy consumption CO_2 emissions of different measuring methods. CO_2 emissions responsibilities of provinces are different based on different methods.

From electricity production perspective, according to Table 4 Column (7), Beijing, Tianjin, Hebei, Shanghai, Zhejiang, Jiangsu and Guangdong are free from CO_2 emissions responsibilities of input electricity, which is underestimated. CO_2 emissions of Beijing, Guangdong and Shanghai are underestimated by 29.5%, 7. 7% and 11.8%, respectively. On the contrary, CO_2 emissions of Shanxi, Inner Mongolia, Hubei, Guizhou and Yunnan are overestimated by 13.0%, 19.6%, 13.4%, 13.8% and 9.5%, respectively.

When revised electric power emission factors are used to calculate total consumed electricity CO_2 emissions, from Table 4 Column (8), we can find that, CO_2 emissions of Fujian, Hubei, Guangxi, Sichuan and Qinghai will be overestimated. Hydroelectricity in these provinces is abundant, and gives priority for their own consumption. The actual electric power emission factors of these provinces are lower than the revised regional average electric power emission factors. Therefore, the assumption that "the electricity of the province is for the use of the province's priority" is reasonable.

When China's regional grid baseline emission factors are used to calculate total consumed electricity CO_2 emissions, from Table 4 Column (9), it can be found that CO_2 emissions of most provinces are higher than TC_2.

If primary energy consumption data is used to measure CO_2 emissions, according to Table 4 column (10), CO_2 emissions of Shanxi, Inner Mongolia, Liaoning, Heilongjiang, Shandong, Shaanxi, Guizhou, Gansu and Xinjiang would be overestimated. As is the case with some secondary energy (e.g., electricity) the resources produced by primary energy are not combusted locally. However, CO_2 emissions responsibilities are underestimated for Beijing, Shanghai, Zhejiang, Fujian and Guangdong.

From the above, it can be seen that, based on the principle of provinces bearing the responsibilities for their energy consumption, TC_2 is more reasonable to calculate interprovincial CO_2 emissions.

Table 4. Average Comparison of Interprovincial Energy Consumption CO_2 Emissions by Different Measuring Methods (2000–2014). Unit: Million tons.

Provinces	TC_1	TC_2	TC_3	TC_4	TC_5	$\frac{TC_1-TC_2}{TC_2}$	$\frac{TC_3-TC_2}{TC_2}$	$\frac{TC_4-TC_2}{TC_2}$	$\frac{TC_5-TC_2}{TC_2}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Beijing	91	129	134	144	92	−29.5%	3.3%	11.0%	−29.2%
Tianjin	116	123	124	131	116	−5.4%	1.0%	7.2%	−5.7%
Hebei	530	563	559	590	487	−5.8%	−0.6%	4.9%	−13.5%
Shanxi	359	318	315	333	654	13.0%	−0.9%	4.8%	105.7%
Inner Mongolia	386	323	276	294	429	19.6%	−14.4%	−8.8%	32.9%
Shandong	579	592	592	631	686	−2.3%	0.0%	6.5%	15.8%
Liaoning	343	369	372	396	457	−7.1%	0.8%	7.1%	23.7%
Jilin	174	170	164	173	184	2.4%	−3.3%	1.5%	8.2%
Heilongjiang	196	194	189	201	262	0.9%	−2.5%	3.3%	34.8%
Shanghai	169	191	196	196	167	−11.8%	2.2%	2.6%	−12.5%
Jiangsu	460	486	488	490	449	−5.4%	0.4%	0.9%	−7.7%
Zhejiang	282	305	334	336	287	−7.8%	9.5%	10.0%	−6.2%
Anhui	223	205	204	204	233	8.9%	−0.7%	−0.3%	13.8%
Fujian	155	152	180	181	135	2.1%	18.5%	19.1%	−10.9%
Jiangxi	115	118	108	132	109	−2.3%	−8.8%	12.0%	−7.5%
Henan	396	398	338	420	427	−0.5%	−15.2%	5.3%	7.1%
Hubei	251	222	255	302	228	13.1%	15.2%	36.2%	2.8%
Hunan	202	204	208	249	193	−0.9%	2.1%	22.1%	−5.2%
Chongqing	110	116	115	137	101	−5.7%	−1.3%	17.9%	−13.0%
Sichuan	224	211	246	301	213	6.4%	16.6%	42.7%	0.9%
Guangdong	381	413	389	533	347	−7.7%	−5.7%	29.1%	−15.9%
Guangxi	123	124	130	163	104	−0.8%	4.4%	31.1%	−16.0%
Hainan	25	25	23	29	32	−0.7%	−7.1%	15.3%	27.0%
Guizhou	177	155	146	177	198	13.8%	−6.3%	13.9%	27.3%
Yunnan	148	135	147	183	141	9.5%	8.5%	35.2%	4.3%
Shaanxi	169	161	151	168	244	5.0%	−6.1%	4.3%	51.3%
Qinghai	29	30	44	52	33	−3.6%	46.6%	74.3%	9.5%
Gansu	108	106	112	128	131	1.8%	5.6%	20.5%	23.7%
Ningxia	89	83	74	84	104	6.4%	−11.7%	1.2%	24.7%
Xinjiang	158	157	147	162	200	0.5%	−6.3%	3.5%	27.5%

3.4. Interprovincial CO_2 Emission Responsibility Analysis

Based on Formula (5) and according to Figure 2, from a production perspective, CO_2 emissions of Beijing in North China are underestimated and the underestimated amount expands gradually, increasing from 22 million tons in 2000 to 45 million tons in 2014. CO_2 emissions of Hebei and Shandong are also underestimated, the underestimated amount rises sharply after 2003 and 2009, reaching 64 and 42 million tons in 2014, respectively. CO_2 emissions of Shanghai, Jiangsu and Zhejiang in Eastern China are also underestimated. Moreover, the underestimated amount expands year by year. CO_2 emissions of Guangdong in the south are seriously underestimated, and the underestimated amount has an annual growth rate of 45%.

Meanwhile, CO_2 emissions of Shanxi and Inner Mongolia in North China and Anhui and Fujian in East China are greatly overestimated. CO_2 emissions of Hubei and Sichuan in Central China and Guizhou and Yunnan in south China are overestimated and the overestimated amount expands year by year.

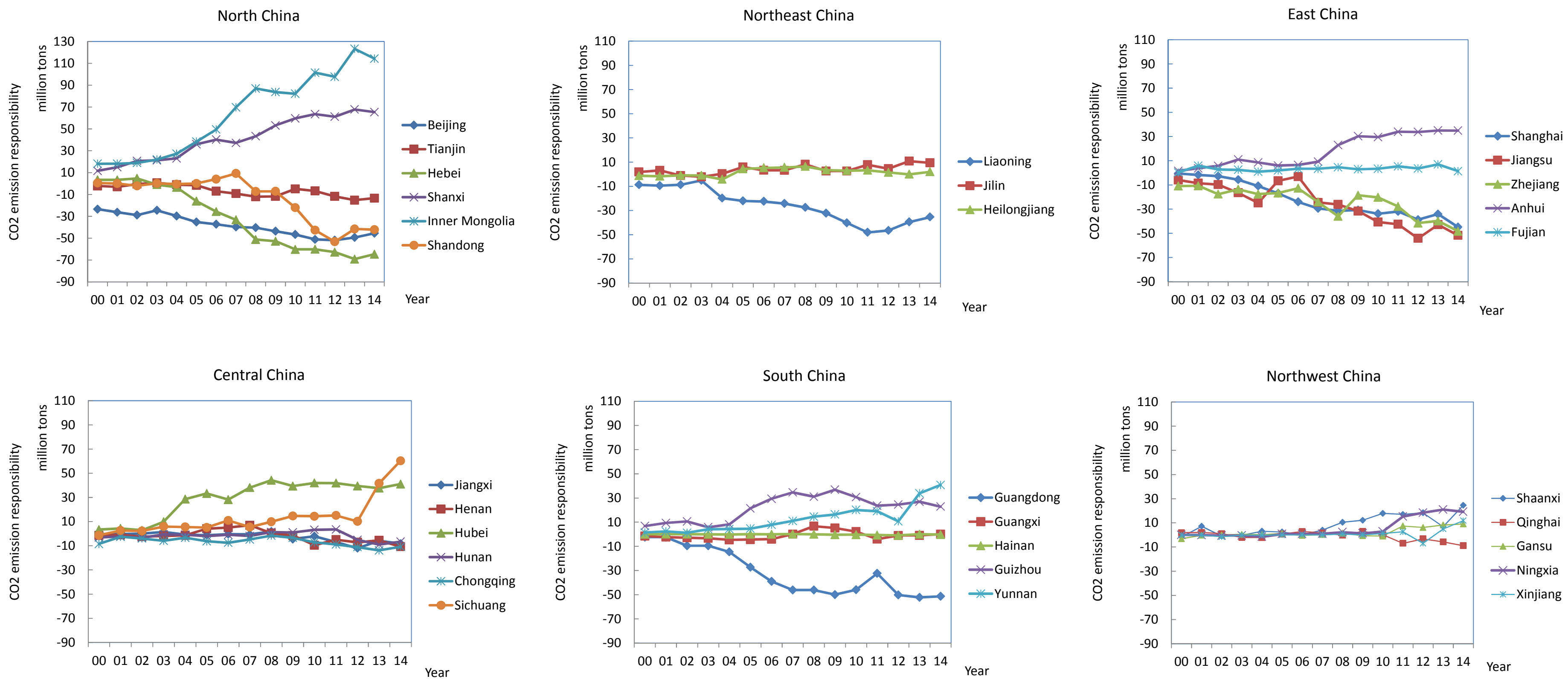

Figure 2. CO_2 emissions responsibility of each province ($TC_1 - TC_2$).

From above, it can be found that, if we do not consider the transfer of CO_2 emissions due to electricity dispatching, for provinces with overestimated CO_2 emissions, the overestimated amount will become greater and greater. For underestimated provinces, the underestimated amount will also increase rapidly. CO_2 emissions responsibilities become increasingly unfair. The reason for this is that interprovincial electric power dispatching in China has an increasing trend year by year. If we measure interprovincial CO_2 emissions based on a production perspective, electricity output provinces will undertake increasingly heavy CO_2 emissions reduction responsibilities which do not conform to actual consumption.

4. Conclusions and Policy Enlightenments

We have measured energy-related CO_2 emissions of provinces in China, especially considering electric power dispatching from both electricity production and consumption perspectives. The obtained results reveal that: (i) Based on the energy balance sheet, the CO_2 emissions of the provincial energy consumption are more favorable than the primary energy consumption method to determine the CO_2 emissions responsibilities of the provinces; (ii) The revised electric power emission factor is more in line with the actual situation of China's regional power grid. The assumption that "the electricity of the province is for the use of the province's priority" can better reflect the characteristics of China's regional grid electricity dispatch; (iii) No matter from which perspective, the overall CO_2 emission of China are almost the same amount. However, interprovincial CO_2 emissions differ greatly from different perspectives. From the production perspective, CO_2 emissions of Beijing, Tianjin, Hebei, Shandong, Heilongjiang, Shanghai, Zhejiang, Jiangsu and Guangdong are underestimated and the underestimated amount increases gradually. CO_2 emissions of Shanxi, Inner Mongolia, Hubei, Sichuan, Guizhou and Shaanxi are overestimated and the overestimated amount has a tendency to expand.

Different methods for CO_2 emissions accounting have their own features. The results calculated by different methods are very different, because of the different level of activity data and different electric power emission factors. Most electricity production provinces are located in middle and west area with undeveloped economy, and most electricity input provinces are economically developed areas. Economically less-developed areas should not pay for pollution of economic developed areas. Therefore, in order to reflect the principle "combination of consumption and responsibility", the following items may be taken into full consideration when measuring CO_2 emissions responsibilities of various provinces: (1) It is better to use comprehensive activity data with classification of fuel variety rather than primary energy consumption data; (2) Secondary energy dispatching should be taken into full consideration when measuring interprovincial CO_2 emissions. This is because it will cause interprovincial CO_2 emissions transfer so that provinces bear the responsibilities for their energy consumption, rather than escape the responsibilities and transfer them to provinces that produced secondary energy. Due to the availability of data, this paper only considers CO_2 emissions transfer triggered by electric power dispatching. CO_2 emissions transfer in the production process of other secondary energy will be one of the follow-up research focusses of this paper; (3) Develop power emission factors in line with the actual situation of the provinces. For revised electric power emission factors in this paper, we comprehensively consider hydroelectricity and thermal electricity produced in the regional grid, which is more practical than China's regional grid baseline emission factors. However, this assumes that electric power produced by the provinces is a priority for their own consumption and electric power is dispatched in the scope of the regional grid. Actual conditions may be much more complicated than this: electric power dispatch is changing all the time. A province can dispatch out electric power to other provinces at a certain moment, the next moment may need to input electric power from other provinces. Moreover, electricity dispatching is not limited in the regional grid. Electric power is more and more important to the development of the economy, and the amount of interprovincial electric power dispatching is very large and complex. Therefore, it is important to determine reasonable electric power emission factors. This is also one of the follow-up key points of this paper.

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