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Emission of CO_2, CH_4 and N_2O from fuel combustion, industrial processes, agricultural and waste treatment sectors in Yangtze River Valley region, China, 1990-2010

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This paper presents a greenhouse gas (GHG) emission inventory in the Yangtze River Valley (YRV) region for the period from 1990 to 2010. IPCC guidelines methods accounting emissions of three main GHG (CO_2, CH_4, and N_2O) from four sectors (fuel combustion, industrial processes, agricultural and waste treatment sectors) were utilised in this study. According to present study the total GHG emissions in the region continued to increase. Energy sector is the largest emissions source in the region. Waste treatment sector is the smallest emissions source. However, the sector has the highest annual growth rate. Economic structure and level of development seem to be the key reasons leading to spatial heterogeneity of GHG emissions. GHG emission intensity continued to reduce in this region, but per capita emissions continued to rise in the region. Implementations of strategies to reduce future GHG emissions are urgently needed, in particular, from fuel consumption and waste treatment sectors.

[Key words: Greenhouse gases, Emission inventory, Yangtze River Valley region, Emission factors]

Introduction

Reporting national inventories of GHG is a fundamental step toward implementation of the UN Framework Convention on Climate Change[1]. A regional inventory is also a critical step in assessing progress towards achieving the goals of reduction/stabilization of the spiraling GHG emissions. There are different inventories assessing regional levels by source which have been described by several authors[2-8]. From these research conclusions we found the regional level estimates can be important for the improvement of the national inventories and for the development of a Local Action Plan to reduce regional GHG emissions[5, 8].

China is the largest emitter of anthropogenic GHG in the world[9]. According to China's "Initial and Second National Communication on Climate Change of The People's Republic of China"[10, 11], the total amount of GHG emissions rose from 36.50 to 74.67 billion tons, in 1994-2005 period. Therefore, policy makers need more accurate inventory of anthropogenic GHG emissions to implement remediation plans. There are many studies focused on GHG emissions from China, but only few studies focusing on GHG emissions from a region of China[12-14]. Thus, regional GHG emission inventories in China have still potential for improvement.

The purpose of this study was to: Evaluate the GHG inventory in the Yangtze River Valley (YRV) region of China; Derive a long-term (1990-2010) trend of three major GHGs of CO_2, CH_4 and N_2O emissions (without Land Use, Land-Use Change and Forestry (LULUCF)) of anthropogenic in YRV region; To elaborate on temporal and spatial changes of GHG emissions. The study result may facilitate policy makers to propose long-term carbon reduction strategies.

Materials and Methods

Study areas

The Yangtze river in China is known as the Changjiang (the long river), originating from the Tibetan Plateau and reaching to the East China Sea coast about 6300 km away[15]. The Yangtze River Valley contains 14 provinces, 2 municipalities, 3 autonomous regions, drainage area over 180×10^4 km^2 (http://zh.wikipedia.org/wiki/). Here, we study 7 provinces and 2 municipalities among them which include Shanghai municipality (SH), Jiangsu province (JS), Anhui province (AH), Jiangxi province (JX), Hubei province (HB), Hunan province (HN), Chongqing municipality, Sichuan province and Guizhou province (GZ). Because Chongqing municipality was divided out from Sichuan Province in 1997, in this study the statistics of them have been merged together to represent single region which define as Sichuan-Chongqing region (SCR). The location and extent of study area show in Fig.1.

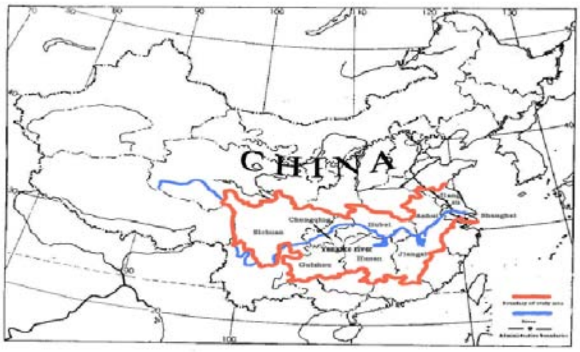

Fig.1 Schematic study area

Methods

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories had provided basic methods for conducting GHG inventories[16]. At its most basic, a GHG inventory is carried out by identifying activities that are responsible for GHG emissions, as certaining the level of each activity, and then calculating the associated greenhouse gas emissions. IPCC inventory methods for each gas-activity pair are stratified into tiers by the intensity of data requirements and model complexity[17]. In this paper, we mostly used Tier 2 and sometimes Tier 1 methods. Detail equations and explanation of methodology can found in IPCC guidelines (e.g. the methods and data necessary to estimate emissions from stationary combustion). An IPCC model typically has the form shown in Equation 1.

$$\mathrm{Emissions}_{RGX} = \sum_{a,b,c} \mathrm{AD}_{RX} \times \mathrm{EF}_{GX,a,b,c}$$

Eq.1

Where: R is the Region; G is the GHG type (e.g., CO_2 type); X is the activity under examination (measured or estimated); a, b, c is activity type (e.g., fuel type); AD is activity data; EF is the emissions factor

Three main GHG (CO_2, CH_4, and N_2O) are taken into consideration in this paper. To compare the radiative forcing of emissions of different gas, The values of global warming potential (GWP) for CH_4 and N_2O used in this article are 21 and 310, respectively (100-year time horizon)[18].

We calculate three GHG emissions from four sectors: energy combustion, industrial processes and product use (IPPU), agricultural activities and the waste treatment processes, for each 5-year period from 1990 to 2010. GHG inventories with detailed information show in Table 1.

Data description

The activity data obtained from relevant statistical data quoted from statistical Yearbooks (e.g. STATIS YEARBOOK of CHINA, China Rural Statistical Yearbook, China Energy Statistical Yearbook, China Industrial Economy Statistical Yearbook, Statistical Yearbook of China's urban construction, Statistical Yearbook of each Provinces and Municipalities).

Emissions factor

For estimating actual emissions from the YRV region, the specific EFs were taken based on measurements drawn from other studies such as data published in peer-reviewed English and Chinese journals between 1990 and 2012.

Table 1. GHG emission broken down by sectors, source categories and emission type

Sectors	Gas type	Source categories		Emission type
Energy	CO_2	Energy consumption†		direct emissions
IPPU	CO_2	Mineral Industry	Cement Production	direct emissions
			Glass Production*	direct emissions
		Metal Industry	Iron and Steel Production	direct emissions
			Aluminium Production	direct emissions
		Chemical Industry	Ammonia Production	direct emissions
Agriculture	CH_4	Rice Cultivation		direct emissions
		Enteric Fermentation in Domestic Livestock‡		direct emissions
		Manure Management		indirect emissions
	N_2O	Synthetic Fertilizers and Crop Residues		directly or indirectly
		Animal Waste		
Waste Treatment	CH_4	Municipal Solid Waste Disposal		direct emissions
		Wastewater Treatment		direct emissions
	N_2O	Municipal Solid Waste Incineration		direct emissions
		Wastewater Treatment		indirect emissions
	CO_2	Municipal Solid Waste Incineration		direct emissions

† In the source categories include coal, petroleum and nature gas combustion and non-combustion emission.

* In the source categories we count The Flat Glass Industry emission only.

‡ In the source categories only include Pigs, Non-dairy cattle , Dairy cattle and Buffaloes.

The Chinese journals were accessed from the Chinese Journal Net (CJN) full-text database. If there were no specific regional EFs for each subcategory, we used the IPCC EFs. Many researchers had published GHG inventories papers about China [14, 19-23]. The specific EFs used for each source category are presented in Tables 2, 3, 4 and 5, respectively.

In terms of energy consumption in China, it is often counted as the standard coal (Stc) (1kg ce=7000kcal= 29,307kJ) and usually other energy source is also converted into standard coal for statistics. In this paper, the energy consumption EF provided by Ma [24].

As to the IPPU sector, it comprises six subcategories, which discussed here (see Table 2). The existing literature usually use default EF data recommended by IPCC for long-term fixed. However, the EFs would change in a longer period for technical progress, especially in long-term. Therefore, we set the EFs are unfixed in the study period.

Numerous studies, such as ZHANG Xiao, WU Gaoming[25], Tieyong[26], Shangguan, Zhang[27] and Chunbao Charles and Cang[28], had discussed the CO_2 emission in Chinese iron and steel industry. In this paper, the CO_2 emission in iron and steel industry estimated based on the analysis of carbonaceous-flow. Here we assume that the pig iron used in steelmaking all regionally produced. Here we discuss the sinter production, iron production and steelmaking processes. The EF of cement was adopted from ZHAO Jianan and Danqing[29] and Hongtao[30]; The EF of glass, here only float glass is discussed, is set the EF to the IPCC default value for 1990, 1995 and 2000 which turned out slightly lower than the EF from TIAN Ying-liang, LIANG Xin-hui[31] for 2005 and 2010. Aluminum category adopted the EF from the IPCC guidelines (Tier 2 methods) for aluminum production and from measurement results reported by Gao Xiang and Cheng[32], CHEN Xi-ping, LI Wang-xing[33]. Due to China's abundant coal resources and relatively small natural gas reserves, coal gasification is the most widely used process in China. The EF for ammonia are taken from IEA[34] which base on three raw materials for the synthesis (Coal, Nature gas, Heavy fuel oil).

Agricultural sector include six categories, which discussed in here. This sector comprises most EFs which are based on country-specific EF report from the National Development and Reform Commission of China government documents and some studies[12, 35-41]. Some unavailable EFs replaced by the IPCC default EFs. Relevant parameters related to CH_4 emission from rice cultivation divided into three levels: geographical distribution; type of rice (early, middle and late-season); type of cropping patterns (single-season, double cropping and winter paddy field). The research area was divided into three parts: Downstream (SH, JS, AH and JX), Midstream (HB and HN) and Upstream (SCR and GZ) of China. The other parameters were taken from IPCC guidelines.

There are many studies estimating CH_4 emissions from enteric fermentation of animal [42-45]. In this paper, the cattle (dairy cattle, non-dairy cattle and buffalo) and pigs are discussion. The EF of Enteric Fermentation is adopted from Xiangdong and Jimin[46] for the characterization of the regional level. Because of the manure management of livestock, there are practically no relevant records about the type and quantity of livestock manure management in China. The EF of Manure Management is used from government documents (unpublished)[47]. The N_2O EF of livestock manure management taken from same source. The N_2O emission from synthetic fertilizers divided into two categories: dry land, paddy field and depending on the type of fertilizer nitrogen fertilizer or compound fertilizer. We discuss emissions from three crop types: rice, wheat and corn. The crop residue incorporated proportions were calculated based on literature data[48-51]. Other parameters are taken from the government documents[47].

The last sector is waste and three categories discussed in this paper: solid waste disposal, waste incineration and wastewater treatment. Considering the region's actual situation, and referring to *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*[20] we estimate CH_4 emission from solid waste disposal based on a Tier 1 version of the FOD method. One key input in the model is the amount of degradable organic matter (DOCm) in the waste disposed into solid waste disposal sites (SWDS). In this paper, we set the proportion of the DOCm in municipal solid waste (MSW) to 74%, special parameter of YRV region. The other parameters used default values suggested by the IPCC.

The CO_2 and N_2O emission from the waste incineration estimate use the IPCC default EFs. The Tier 2 method of IPCC guidelines used to estimate CH_4 emission from wastewater. The specific EF of YRV region is taken fromSong, Luo [52]. Due to lack of data, we use IPCC default method to calculate EF for N_2O emission from wastewater.

Results

Carbon dioxide emissions

The total CO_2 emissions from the YRV region have increased from 711.33 Tg in 1990 to 3192.95 Tg in 2010, and annual growth rate is 8.2%. The main reasons for the changes were energy consumption demand, which continued to rise and high proportion of fossil energy consuming. Statistics data show that fossil energy consumption increased from 241.75 Tg Stc to 1085.72 Tg Stc, in 1990-2010. The CO_2 emission increased from 577.78 Tg to 2594.88 Tg in 1990-2010. The IPPU sector CO_2 emission also increased rapidly from 133.56 Tg in 1990 to 596.07 Tg in 2010, at annual growth rate of 8.2%.

The first waste incineration plant of the YRV region built in SH at 2001. Until the end of 2010, there were 15 wastes incineration plants, with total capacity of 13715 ton/day, had built.

Table 2. The EFs of IPPU sector (metric tons CO_2 / metric tons product).

Source Categories	1990	1995	2000	2005	2010	Default of IPCC
Cement	0.53	0.53	0.53	0.53	0.53	0.52
Glass	0.21	0.21	0.21	0.18	0.18	0.21
Iron	1.61	2.74	1.74	1.26	1.07	1.35
Steel	3.38	2.65	2.16	1.91	1.87	1.06
Aluminium*	1.81	1.81	1.81	1.81	1.81	1.60
Ammonia	3.95	3.95	3.95	3.95	3.95	2.10

*Primary aluminum production mostly employed large-scale carbon anode Prebake technology in China.

Table 3. The EFs of farming source categories.

Sources	Gas	SH	JS	AH	HB	JX	HN	SCR	GZ	IPCC
Paddy*	CH_4	168.90	283.80	277.67	270.91	320.00	331.25	267.14	272.00	130
dry land (EF_1)†	N_2O	0.0040~0.023								0.10 (0.03~0.30)
Paddy field (EF_{1FR})†		0.0067~0.036		0.0007~0.021		0.0002~0.022		0.00030~0.0052		
VrD‡	N_2O	0.010 (0.002 - 0.05)								
E/R^K		0.0075 (0.0005 - 0.025)								

VrD: N volatilisation and re-deposition, E/R: eaching/runoff; * Units is mg /m^{-2} d^{-1}; † Units is kg N_2O–N (kg N input)$^{-1}$; ‡ Units is kg N_2O–N (kg NH_3–N + NOX–N volatilised)$^{-1}$; K Units is kg N_2O–N (kg N leaching/runoff) $^{-1}$.

Table 4. The EFs of animal husbandry source categories (kg·head^{-1}·a^{-1}).

Sources	Gas	dairy cattle	nondairy cattle	buffalo	pigs
EFL	CH_4	68.0	47.8	55.0	1.0
MM		7.8	3.8	5.1	5.0
IPCC- EFL		61.0	47.0	55.0	1.0
IPCC- MM		15.0	1.0	2.0	4.0
AW-East China	N_2O	2.1	0.8	0.9	0.2
AW-South China		1.7	0.8	0.9	0.2
AW-Southwest China		1.9	0.7	1.2	0.2

EFL: Enteric Fermentation in Domestic Livestock; MM: Manure Management; AW: Animal Waste. East China include SH, JS, AH, JX; South China include HB, HN; Southwest China include Chongqing, Sichuan and GZ.

Table 5. The EFs of Waste Treatment sector.

Sources	Gas	emission factors
MSW landfill- livelihood*	CH_4	0.90 tone CH_4/ tone SWD
WWT- livelihood		0.14 kg CH_4 / kg BOD
WWT- Industry		0.13 kg CH_4 / kg BOD
MSW Incineration	N_2O	50 gN_2O/tone SWD
WWT		0.005 kg N_2O-N/kg BOD
MSW Incineration	CO_2	95% Combustion efficiency

*The FOD model built on an exponential factor that describes the fraction of degradable material, which each year is degraded into CH_4 and CO_2. Set the CH_4 potential Lo as EF.

In regional waste incineration capacity from 0.27 Tg (2001) rose to 7.35 Tg (2010). CO_2 emissions have increased from 0.073 Tg to 1.99 Tg at annual growth rate of 44.5%.

The CO_2 emissions proportion of the all source categories in each province show in Table 6. The result show that average proportions of energy use occupy about 81.2% of total emission. JX has the minimum energy emissions, about 70.8%. GZ has the maximum emissions, approx. 88.6%. Average proportion of IPPU sector accounts for about 19% of total emission. In this sector, pig iron production is the largest source, followed by cement production, crude steel making, ammonia, aluminum and flat glass production (see relative proportions in Fig.2.). The result indicates that the proportions of CO_2 emissions related to the IPPU sector gradually decreased from SH to GZ. The proportion of the steel industry gradually decreased, while the cement and ammonia production industry showed a gradual increase in the relative proportion. Waste incineration is the smallest source, with a relative percentage of less than 0.1%.

Methane emissions

Total amount of methane emitted from the YRV region increased from 231.86 CO_2-eq Tg in 1990 to 811.47 CO_2-eq Tg in 2010. The CH_4 emission from Agriculture sector was on the fluctuations from 231.86 CO_2-eq Tg in 1990 to 232.19 CO_2-eq Tg in 2010. CH_4 emission from Waste Treatment sector increased from 377.00 CO_2-eq Tg in 2000 to 579.27 CO_2-eq Tg in 2010. Average annual growth rate of Agriculture sector is -0.005%; the rate of Waste Treatment sector is 16.2%.

The CH_4 emissions proportion of five categories in each province shown in Table 7. Largest CH_4 emission source is MSW Landfill, amounting to about 53.7%. CH_4 emission from paddy, Enteric Fermentation and Manure

Management had similar percentage contributions, of about 27.2%, 9.0% and 9.6%. Wastewater Treatment is the smallest source, constituting only 0.51% of the total emissions. Agricultural methane emissions mainly influenced by the impact of rice cropping systems (cultivating rice, planting double-crop rice and even planting three quarters rice). The type and number of breeding animals mainly affected CH_4 emission from Enteric Fermentation and Manure Management. Economically developed regions (e.g. SH and JS) are breeding more cattle; economically developing regions (e.g. SCR and GZ) are breeding more non-dairy cattle and buffalo. As to Manure Management, pigs are the major source of CH_4 emissions. The detail results show in Table 8.

Nitrous oxide emissions

The total amount of N_2O emitted from the YRV region increased from 41.69 CO_2-eq Tg in 1990 to 67.64 CO_2-eq Tg in 2010. Fig.3. shows the proportion of N_2O emissions for each sector from 1990 to 2010. Relative to the other two types of GHG emission changes, N_2O emissions growth was relatively slow. The N_2O emission from Agriculture sector had slower growth from 1990 to 2010, and the average annual growth rate about 2.5%. Because the Waste Treatment sector data are unavailable before 1995, the statistics in this study for the N_2O emission from Waste Treatment sector based only on 2000, 2005 and 2010. The average annual growth rate was about 1.6% in 2000-2010.

The vast majority of the total N_2O emissions are from the agricultural sector, accounting for 99.2%. The N_2O emission from waste disposal accounts for only less than 1% of the N_2O total emissions. Furthermore, the sector analysis indicates the Synthetic Fertilizers and Crop Residues are the largest source for N_2O emission, accounted for about 62.6%. The Animal Waste Treatment is the second source, accounting for about 36.7%; the Waste Treatment sector is a very small source for N_2O emission that accounted for 0.74%, while the solid waste incineration accounted for only 0.04%.

Regarding the composition of each category, SCR and GZ showed higher N_2O emission from animal waste treatment category than others. The other provinces show higher emissions from synthetic fertilizers and crop residues category emissions. The results of N_2O emission from the provinces are show in Table 9. Interestingly the annual growth rate of SH was negative, and HB province had the largest annual growth rate. The main reason for these changes is the agricultural economy.

Aggregate emission analysis

The changes of GHG emissions produced by anthropogenic activities in the YRV region showed strong annual growth (about 7.7% per year). In particular after year 2000 a very significant growth trend (of about 8.2% per year). However, if waste disposal sector's GHG emissions are excluded, the annual growth rate of the total emissions decreases to 6.8%.

Table 6. The CO_2 cumulative emissions proportion of all source categories in each province.

	SH	JS	AH	JX	HB	HN	SCR	GZ
Energy	82.19%	82.48%	82.81%	70.83%	77.76%	83.76%	81.14%	88.63%
IPPU	17.74%	17.44%	17.17%	29.17%	22.24%	16.24%	18.83%	11.37%
Crude steel	5.22%	1.51%	2.27%	2.38%	3.30%	1.28%	1.69%	0.65%
Pig iron	11.01%	6.74%	8.09%	8.71%	8.17%	5.03%	5.10%	2.64%
Aluminum	0.00	0.02%	0.00	0.00	0.13%	0.06%	0.13%	0.55%
Cement	0.97%	7.26%	5.98%	11.08%	6.60%	6.65%	7.41%	4.44%
Float glass	0.02%	0.05%	0.01%	0.03%	0.05%	0.03%	0.03%	0.00
Ammonia	0.52%	1.87%	0.82%	6.97%	4.01%	3.19%	4.47%	3.09%
WI	0.06%	0.08%	0.02%	0.00	0.00	0.00	0.03%	0.00

WI: Waste Incineration

Table 7. The CH_4 emissions proportion of five source categories in the provinces.

	SH	JS	AH	JX	HB	HN	SCR	GZ	Total
Paddy	2.17%	20.40%	38.33%	48.03%	19.57%	42.11%	23.06%	20.44%	27.15%
Manure Management	1.47%	5.75%	9.67%	8.27%	7.34%	11.63%	16.78%	11.46%	9.63%
MSW Landfill	95.50%	71.37%	39.08%	34.68%	66.12%	37.44%	44.36%	41.58%	53.70%
Wastewater Treatment	0.36%	0.49%	0.52%	0.43%	0.47%	0.55%	0.62%	0.55%	0.51%
Distributed of provinces	8.22%	16.77%	8.54%	10.18%	15.25%	16.21%	19.28%	5.56%	

Table 8. The CH_4 emission from Livestock categories in the provinces (10 billion g).

	Enteric Fermentation				Manure Management			
	Cattle	non-dairy cattle	buffalo	pig	Cattle	non-dairy cattle	buffalo	pig
SH	2.14	0.00	0.11	2.88	0.24	0.00	0.01	14.54
JS	3.53	7.86	6.26	23.11	0.40	0.62	0.58	116.50
AH	1.24	84.54	25.59	18.23	0.14	6.63	2.38	91.90
JX	1.17	54.58	32.12	18.99	0.13	4.28	2.98	95.70
HB	1.51	47.62	46.80	25.55	0.17	3.74	4.35	128.76
HN	1.33	68.96	50.11	43.74	0.15	5.41	4.66	220.44
SCR	3.96	209.94	70.65	73.92	0.45	16.47	6.56	372.55
GZ	0.97	100.40	62.46	12.73	0.11	7.88	5.80	64.16
Total	15.86	573.88	294.10	219.16	1.81	45.02	27.32	1104.55

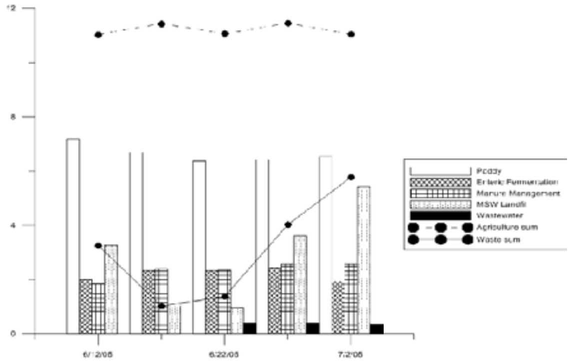

Fig. 2. The proportion of CO_2 emission from each IPPU categories of each province.

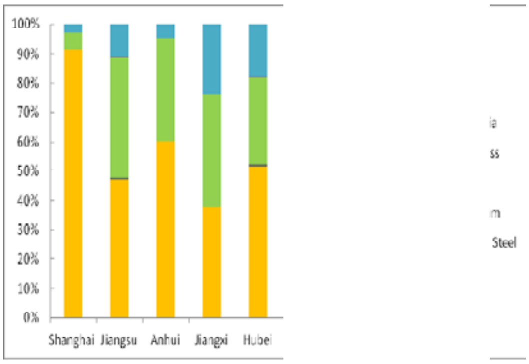

Fig. 3. The CH4 emissions from each sector (Tg CH_4)

Table 9. The N_2O Emissions distribution in the provinces (10 billion g).

	SH	JS	AH	JX	HB	HN	SCR	GZ	Total
1990	0.46	3.96	2.47	1.61	2.58	2.63	4.89	1.27	19.85
1995	0.49	5.53	4.12	2.22	3.89	3.47	5.92	1.63	27.27
2000	0.48	5.87	4.08	2.06	3.81	3.89	6.17	1.84	28.20
2005	0.35	5.99	4.45	2.28	4.36	4.52	6.78	1.84	30.57
2010	0.31	5.99	4.81	2.47	5.21	4.55	6.86	2.01	32.21
Total	2.09	27.34	19.93	10.64	19.85	19.06	30.62	8.59	
AGR	-2.03%	2.21%	3.58%	2.29%	3.76%	2.93%	1.80%	2.43%	2.58%

AGR: Average growth rate

Table 10. Comparison of GHG emission estimates from Chinese from different studies

Sector	Data sources	1990	1995	2000	2005	2010	CCL
Energy	This study*	0.96	0.48	0.30	0.28	0.18	
	CDIAC[1]	1.32	0.55	0.34	0.31	0.23	0.99
	[53]2	1.77	1.34	0.90	0.94	0.79	0.98
Energy (metric tons of CO_2 per capita)	This study	2.46	3.50	3.34	5.82	8.20	0.99
	CDIAC[1]	2.15	2.74	2.68	4.43	6.18	
	This study	1.44	2.06	2.03	3.63	5.33	0.99
	[53]	1.95	2.48	2.41	3.88	5.39	
Agriculture (CH_4 Tg)	This study	11.04	11.44	11.08	11.45	11.06	0.78
	Chao Fu[4]	16.37	18.49	18.26	19.39		
Livestock (Tg CO_2-eq)	This study	106.85	131.85	130.49	139.82		0.89
	J.B. Zhou[5]	238.93	258.08	277.23	296.38		
N_2O from cropland(Gg)	This study	11.50	16.82	17.58	19.05		0.98
	B. Gao[6]	19.31	24.78	27.43	30.14		
SWDS (N_2O Gg)	This study	312.3	408.6	1181.8	3695.7	5428.6	0.96
	QU Shen-ning[7]	8012.2	10627.3	12734.8	15439.3	18694.8	

1. The data are calculated from CDIAC (thousand metric tons of CO_2 per billion CNY) (http://cdiac.ornl.gov/trends/emis/meth_reg.html); 2. The data cite from[34], (kg CO_2 per US$ using 2005 prices); 3. The data without field burning of crop residues in this comparison; 4. The data were calculated from the Chao Fu study; 5. The data without the CH_4 emission from country land SWDS emission. *. This study data unit of measure is thousand metric tons of CO_2 /billion CNY.

From the cumulative GHG emissions, energy sector is the largest source (48.8%), industry sector is the second source (29.5%), agriculture sector is the third source (11.6%) and waste disposal sector is the minimum source (10.2%). As a proportion of the three greenhouse gases: CO_2 accounted for 73.3%, CH_4 for 22.9% and N_2O for 3.8%. In terms of the provinces, the proportion of total emissions consists of SH 8.2%, JS 16.8%, AH 8.5%, JX 10.2%, HB 15.3%, HN 16.2%, SCR 19.3% and GZ 5.6%. $CO_{2\text{-eq}}$ proportion of SH and HB shows a decreasing trend from 15% and 17% to 9% and 13%, respectively. $CO_{2\text{-eq}}$ proportion of JS show increasing tendency from 16% to 24%. The reason for this change may be the difference in the annual growth rate of the GHG emissions for each province. The proportion distribution of three type gases emitted from these provinces is mainly affect by the economic structure and development level of each province.

Discussion

Comparison of GHG emissions with other studies

The direct anthropogenic GHG emissions in China have been widely explored. Most of the articles study the situation as a whole or per a sector of the national emission scenarios. However, only few of these articles discuss regional emission scenarios. In Table 10, the estimates presented in our article compared with other literature published after 2000. Results from this study result seem consistent with the CDIAC[54] and IEA database data[34]. The result of our study was lower than that reported by Zhang, Mu[55]. Results show energy sector CO_2 intensity about 1.90 (million tons/billion CNY) in 1991, 1.01(Mt/bC) in 2006.

Price, Sinton[56] report the carbon intensity of Chinese steel sector reaching 1.03 ton C/ton steel in 1996. While Bai, Li[57] report that CO_2 emission volume from Cement, Iron and Steel and Ammonia source categories (about 154.77 Mt, 103.71 Mt and 41.16 Mt total CO_2, respectively) in 2004. In this study, CO_2 emissions from same categories in 2005 are 121.48Mt, 287.53Mt and 57.23Mt, respectively. Despite the obvious discrepancy between the two results, both are in the same order of magnitude. The difference between them may be due to different emission factors and the activity data from different years.

Fu and Yu[35] used the Tier 2 method presented in IPCC Guidelines[16] to study the CH_4 emissions from rice cultivation, livestock enteric fermentation and waste management. Yamaji, Ohara[42] examined the geographic distribution of CH_4 emissions from livestock in Asia in 2000. Zhou, Jiang[58] presented a systematic estimation of CH_4 and N_2O emission during 1949–2003, based on the local measurement and IPCC guidelines. Lu, Huang[39] used empirical model with country-specific EFs to estimate direct N_2O emissions from fertilized fields in China. Gao, Ju[40] estimated direct N_2O emissions from both paddy fields and uplands using these localized EFs. The comparisons of the EFs from these authors with this report are show in Table 10. Although the scope of this study was less wide, the time series trend yields a high correlation coefficient.

Xing, You-Fei[19] estimated CH_4 and N_2O emissions from sewage treatment plants based on the IPCC default methodology and showed CH_4 emissions at a low rate, while N_2O emissions increased annually at the highest annual growth rate. This result is consistent with our results. In Table 10 we compared our study with Shen-ning and Dan-hui[59] result yielding a high correlation coefficient. This suggests that the result of this paper might be representative of the national trends.

Analysis of CO_2-eq emissions in YRV region

The economy and population development of the YRV region in 1990-2010, show in Table 11, showing the YRV region's CO_2-eq emissions per capita at a sustained increase from 1990 to 2010 that exceeded Brazil and India after 2005. However, the increase was not as high as in China and United States in the same period. Annual growth rate of the YRV region was higher than in the other countries, second only to the China national level. The CO_2-eq emissions per GDP in the YRV region continued to decline between 1990 and 2005. Xu Xinhua[12] estimated the GHG emissions intensity of JS Province in 1990, at approximately 4770 tons of CO_2 per million USD. Wang, Ma[60] estimated the CO_2-eq emissions intensity of SH at 2249 and 1519 tons of CO_2 per million USD in 2000 and 2005, respectively. Our study showed consistent values and trends of emission per GDP. China had released two national reports to National Communications on Climate Change (NCCCC) in 1994 and 2005, respectively. The detailed results are presented in Table 12. It can be seen that the proportion of the three gases of the YRV region in 1995 was close to the national level in 1994. However, in 1995, the CH_4 proportion of the YRV region was higher than the national level and the other gas proportion were lower than the national level. Emission trends in the energy, IPPU and agricultural sector were the same as the national change. The emission change trend of the waste sector was opposite to the national change. In particular, the rate of agricultural sector GHG emissions declined more than the national. For example, the Yangtze River rate of GHG emissions from agricultural sector dropped more than the percentage change in the country, in ten years.

Table 11. The change of economy, population and GHG

		1990	1995	2000	2005	2010	AGR
GDP	YRV	6030.57	19616.63	31888.18	62358.58	142120.84	0.181
(billion CNY)	China	18667.8	60793.7	99214.6	184937.4	401202.0	0.175
Population	YRV	48028	50214	58141	59448	60026	0.012
(10k Population)	China	114333	121121	126743	130756	134091	0.008
GHG emissions	YRV	3.19	4.27	4.09	6.70	9.13	0.054
per capita[1]	China	3.17	3.87	3.82	5.55		0.041
(metric tons of	Brazil	4.62	4.73	5.38	5.43		0.011
CO_2 equivalent	India	1.30	1.44	1.58	1.70		0.019
($mtCO_2$-eq) per person)	USA	23.95	23.53	24.19	23.33		-0.002
GHG emissions	YRV	11103.94	7641.60	4825.50	4192.54	2115.67	-0.067
intensity[2]	China	2876.39	2092.53	1430.65	1350.06		-0.053
($mtCO_2$-eq per	Brazil	643.99	612.63	680.05	638.52		-0.001
million $intl)	India	1048.58	989.90	893.01	740.87		-0.025
	USA	750.22	694.15	611.10	548.57		-0.022

1. Data from CDIAC (in 1990-2005) and IEA Statistics (in 2010). This section includes only the energy sector emissions data.

2. Data from World Resources Institute, Climate Analysis Indicators Tool (WRI, CAIT). 2012. CAIT version 9.0. Washington, DC: World Resources Institute. Available online at: http://cait.wri.org; AGR: Average growth rate

The detailed results are presented in Table 12. It can be seen that the proportion of the three gases of the YRV region in 1995 was close to the national level in 1994. However, in 1995, the CH_4 proportion of the YRV region was higher than the national level and the other gas proportion were lower than the national level. Emission trends in the energy, IPPU and agricultural sector were the same as the national change. The emission change trend of the waste sector was opposite to the national change. In particular, the rate of agricultural sector GHG emissions declined more than the national. For example, the Yangtze River rate of GHG emissions from agricultural sector dropped more than the percentage change in the country, in ten years.

Uncertainties

The GHG emissions in YRV region are associated with large uncertainties because of different EFs and the methodologies used in this estimation. Furthermore, many analysts have viewed official Chinese statistics with skepticism, and there has been suspicion that politics motivated adjustments in the reported data[61, 62]. Nevertheless, much of the data on which we depend is ultimately from the Chinese National Bureau of Statistics, and any inaccuracies in those data would propagate to our estimates of GHG emissions. On the other hand, the lack of the waste sector data before 2000, can easily lead to a bias and missing values. We hope that this uncertainty can be acceptable in the initial inventories, which will need improvement as more measurements become available.

Table 12. The proportion of the three Gas and the contribution of four sectors

		CO_2	CH_4	N_2O	Energy	Industry	Agriculture	Waste
1994	NCCCC Ⅰ	73.05%	19.73%	7.22%	74.13%	6.97%	14.91%	4.00%
1995	This paper	76.66%	17.27%	6.08%	48.30%	11.10%	18.09%	0.48%
2005	NCCCCⅡ	81.83%	12.77%	5.39%	79.00%	8.25%	11.23%	1.52%
2005	This paper	73.06%	23.64%	3.31%	54.16%	11.46%	10.47%	2.76%

NCCCC is National Communications on Climate Change. There are two NCCCC report of China.

Conclusions

This study evaluated CO_2, CH_4 and N_2O emissions in YRV region during 1990 – 2010. We found the regional GHG emissions increased 4 times, in the period. Energy sector was the largest source, followed by the IPPU sector, the agricultural sector and the waste treatment sector. Temporal and spatial distributions of GHG emission in YRV region could mainly be attributed to the economic structure and development level of each province. The results showed that GHG emissions per capita continue to increase, while the intensity of GHG emissions continues to decline.

What do we expect for the future? Facing the increasingly GHG emissions, must reduce energy consumption and adjust economic structure. Accelerate low carbon economic and technology development. Strengthen management of waste treatment emissions. Establish regional and national carbon emissions trading market.

These results, despite the uncertainties, can be valuable for attracting attention to the important environmental and health issues related to GHG emissions in China. Future work should focus on more regional measurements and on the development of approaches to improve the accuracies of the current inventories. The work can serve guidance for policy makers in undertaking the remediation strategies to protect the environment.

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