4th International Workshop
on Uncertainty in Atmospheric Emissions

7-9 October 2015, Krakow, Poland

PROCEEDINGS

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About the Workshop

The assessment of greenhouse gases and air pollutants (indirect GHGs) emitted to and removed from the atmosphere is high on the political and scientific agendas. Building on the UN climate process, the international community strives to address the long-term challenge of climate change collectively and comprehensively, and to take concrete and timely action that proves sustainable and robust in the future. Under the umbrella of the UN Framework Convention on Climate Change, mainly developed country parties to the Convention have, since the mid-1990s, published annual or periodic inventories of emissions and removals, and continued to do so after the Kyoto Protocol to the Convention ceased in 2012. Policymakers use these inventories to develop strategies and policies for emission reductions and to track the progress of those strategies and policies. Where formal commitments to limit emissions exist, regulatory agencies and corporations rely on emission inventories to establish compliance records.

However, as increasing international concern and cooperation aim at policy-oriented solutions to the climate change problem, a number of issues circulating around uncertainty have come to the fore, which were undervalued or left unmentioned at the time of the Kyoto Protocol but require adequate recognition under a workable and legislated successor agreement. Accounting and verification of emissions in space and time, compliance with emission reduction commitments, risk of exceeding future temperature targets, evaluating effects of mitigation versus adaptation versus intensity of induced impacts at home and elsewhere, and accounting of traded emission permits are to name but a few.

The *4th International Workshop on Uncertainty in Atmospheric Emissions* is jointly organized by the *Systems Research Institute of the Polish Academy of Sciences*, the Austrian-based *International Institute for Applied Systems Analysis*, and the *Lviv Polytechnic National University*. The 4th Uncertainty Workshop follows up and expands on the scope of the earlier Uncertainty Workshops – the *1st Workshop* in 2004 in Warsaw, Poland; the *2nd Workshop* in 2007 in Laxenburg, Austria; and the *3rd Workshop* in 2010 in Lviv, Ukraine.

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Carbon Emission Inventory Calculation and Analysis based on Coal Lifecycle

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Abstract

Coal is the main source of GHG emission in China. To systematic and comprehensive estimate the GHG emission of coal lifecycle, according to the intergovernmental panel on climate change (IPCC) method, the paper using Monte Carlo simulation, calculates carbon emission in each stage of coal lifecycle, and quantifies the uncertainties in results. The results show that GHG emission in coal mining, transportation and consuming is 8526.67 million tons, 3328.35 million tons and 1356723.59 million tons respectively in 2011, and the whole GHG emission in coal lifecycle is 1367186.72 million tons. The uncertainty analysis shows that coal mining contains the greatest uncertainties, the uncertainty of GHG emission from the coal lifecycle in 2011 is (-5.09%, 4.85%).

Keywords: Carbon emission inventory, Monte Carlo, Uncertainty

1. Introduction

Coal has been the dominant source of energy used to fuel the rapid economic development of China in the past two decades. In 2011, China relies on coal for approximately 70% of its energy. However, during the production and consumption process of coal, it has also producd significant impact on its physical environment, of which, the GHG emissions are well known.

Currently many researches have done on GHG emission inventories, but most of these researches have done on city level, and seldom researches have done on GHG emission according to different industries. Shi Huading etc., put forward the basic principles of GHG inventory methods of power sector, and established GHG inventory methods framework on power sector according to national conditions in China. Zheng Shuang proposed methodology about coalbed methane GHG emissions inventories. To our best knowledge, the studies on on GHG emission inventory of coal lifecycle is is rarely found in the literature.

2. Research Method

To calculate the emission inventory, the method is comes from "2006 IPCC Guidelines for National Greenhouse Gas Inventories" which is a relatively complete theory of GHG emissions and emission estimation methods and processes. It has been adopted by many countries now and "IPCC National Greenhouse Gas Inventory Good Practice and Uncertainty Management". As to perform quantitative uncertainty analysis, the paper adopted the Monte Carlo simulation.

3. Greenhouse gas inventories of China's coal industry

The coal lifecycle consists of mining, washing, transportation, conversion and utilization. The GHG emission from each stage will be introduced in this section.

3.1 GHG emission from coal mining

Methane will dissipation during the geological process of coal formation, until some residual methane in coal is released from coal mining. In 2011, the total production of the coal in China is 3.888 billon tons, of which, 2.545 billion tons was produced through underground mining and 1.343 billion tons was through open pit. According to the provision in "Good Practice", there is 5% error in coal production register production, therefor we set the mining production through underground and open pit as triangular distribution. For simplicity, we set the production increase 5% over the register production as the maximum production, and the production decrease 5% as the minimum production, and the register production find in publication is the most possible values. The low, average and high CH_4 emission factors for underground mining are 16.75kg/t,12.06kg/t and 6.7 kg/t respectively using global average value. The low, average and high CH_4 emission factors for surface mining are 2.0kg/t,1.2kg/t and 0.3kg/t respectively using global average value. Related parameters are shown in Table 1.

Equation for estimating CH_4 emissions from coal mining is as follows:

$$CH_4\ emissions = \sum_i Ai \times EF_i * GWP \qquad (1)$$

Ai is the activity level of mining way i, EF_i is emission factor of transportation mode i. GWP is global warning potential, and the GWP of CO_2 is 1, the GWP of CH_4 is 21, the GWP of N_2O is 275. Using Crystal Ball software, through 4000 times Monte Carlo simulation calculation, the total CH_4 emission in coal mining is 85.2667 million tons CO_2 equivalent, 95% confidence interval is (4783.05, 12502.50).

Table 1 Coal mining methane emissions related parameters

	Underground mining	**Surface mining**
Activity level probable value (10 thousand tons)	254502.74	134321.23
Activity level maximum value (10 thousand tons)	267227.88	141037.29
Activity level minimum value (10 thousand tons)	241777.60	127605.17
Emission factor probably value (kg/t)	12.06	8.04
Emission factor maximum value (kg/t)	16.75	13.40
Emission factor minimum value (kg/t)	6.70	2.01

3.2 GHG emission from coal transportation

The coal transportation in China mainly relies on railway, highway and waterway. In China's coal railway transportation, there are two kinds of locomotive, diesel locomotive and electric locomotive, which consumption oil and electricity respectively. Electricity is secondary energy, so we only take diesel locomotive into consideration, which use diesel as the main fuel. Coal transportation through highway usually uses medium-duty truck or heavy trucks which can load more than 20 tons, and most of them use diesel. Waterway transportation also uses ships mainly driven by diesel locomotive, from barge to large-scale ocean cargo ship.

In China, 2270.26 million tons coal was transported by railway in 2011. Its average haul distance was 645 km. Thus the volume of the coal circular flow was 1464.33177 billion tons kilometer, and 53.6% was transported by diesel locomotive and 46.4% by electric locomotive. The circular flow volume of diesel locomotive was 784.874 billion tons kilometer. In the railway transportation, the diesel locomotive consume 26.8 kg diesel each ten thousand tons kilometer, and railway transportation totally consumed 2103463.10 tons diesel. In China 0.35 billion tons coal was transported by highway, 2011. Its average haul distance was 250 km. Thus the volume of the coal circular flow through highway transportation was 87.5 billion tons kilometer. The diesel consumed by highway transportation is 6 kg each hundred tons kilometer, and highway transportation totally consumed 5250000 tons diesel. In China 0.65 billion tons coal was transported by waterway, 2011. Its average haul distance was 1768.75 km. Thus the volume of the coal circular flow through waterway transportation was 1149.688 billion tons kilometer. The diesel consumed by waterway transportation is 21.5 kg each ten thousand tons kilometer, and waterway transportation totally consumed 2471828.13 tons diesel. All kinds of GHG emission factor using the default values in IPCC 2006. Coal transportation parameters of activity level and emission factor are shown in Table 2.

Table 2 Coal transportation parameters of activity level and emission factor

Item	Railway transportation	Highway transportation	Waterway transportation
Diesel activity level probable value (t)	2103463.09	5250000.00	2471828.13
Diesel activity level minimum value (t)	1998289.94	4987500.00	2348236.72
Diesel activity level maximum value (t)	2208636.24	5512500.00	2595419.53
CO_2 emission factor default value (kg/t)	3211.92	3211.92	3211.92
CO_2 emission factor minimum value (kg/t)	3146.90	3146.90	3146.90
CO_2 emission factor maximum value (kg/t)	3242.26	3242.26	3242.26
CH_4 emission factor default value (kg/t)	0.18	0.17	0.30
CH_4 emission factor minimum value (kg/t)	0.07	0.07	0.15
CH_4 emission factor maximum value (kg/t)	0.45	0.41	0.46
NO emission factor default value (kg/t)	1.24	0.17	0.09
NO emission factor minimum value (kg/t)	0.62	0.06	0.05
NO emission factor maximum value (kg/t)	3.72	0.52	0.21

Table 3 GHG emission from coal transport (10 thousand CO_2 equivalent)

	Calculated value	Minimum value	Maximum value
Total CO_2 emission	3142.88	2989.98	3300.89
Total CH_4 emission	5.28	2.55	8.09
Total NO emission	168.25	69.17	297.38
Total emission	3328.35	3096.73	3574.06

According to IPCC (2007) recommendation, the equation for estimating CH_4 emissions from coal transportation is as follows:

$$E=\sum_i \sum_j A_i *EF_{ij}*GWP_{ij} \tag{2}$$

In the equation, E is GHG emission of coal, Ai is activity level of fuel i (t); EF_{ij} is emission factor of GHG j from fuel i (t/t fuel), GWP_{ij} is global warning potential of GHG j from fuel i. Using Crystal Ball software, the total GHG emission in coal transportation is calculated through 4000 times Monte Carlo simulation. The results are shown in Table 3.

3.3 Carbon emission inventory from the coal consumption

In the carbon emission inventory, Coal combustion is the main source of greenhouse gases .According to the availability of emission factors, we adopted the reference method recommended in the "Guide" and the latest emission factors announced by the National Bureau of Statistics. Set the data provided by the Statistical Yearbook as the most probable value in the triangular distribution. Set the date increase 5% over the probable value as maximum and -5% as minimum. The coal activity data is shown in Table 4.

Table 4 Coal consumption data in triangle distribution of 2011(10,000 tons)

Source category	Probable value	Minimum	Maximum
Raw coal	346799.81	329459.82	364139.80
Washed coal	49101.65	46646.57	51556.73
Briquette	1019.20	968.24	1070.16
Coke	38163.29	36255.13	40071.45
Other washed coal	11962.94	11364.79	12561.09

According to the recommendation of IPCC (2006), we use the emission factors in Table 5 provided by Chinese Academy of Engineering as the basis of calculation.

Table 5 Coal emission factors

Source category	Raw coal	Washed coal	Other washed coal	Briquette	Coke
CO_2 emission factor defaults （kg CO_2/t）	2.009	2.531	1.004	1.689	3.044
minimum	1.9086	2.4045	0.9538	1.6046	2.8918
maximum	2.10945	2.65755	1.0542	1.77345	3.1962
CH_4 emission factor defaults （kg CH_4/t）	20.908	26.344	10.454	17.584	28.435
minimum	19.86	25.03	9.93	16.7	27.01
maximum	21.953	27.661	10.977	18.463	29.857
N_2O emission factor defaults （kgN_2O/t）	31.362	39.516	15.681	26.376	42.653
minimum	29.794	37.54	14.897	25.057	40.52
maximum	32.93	41.492	16.465	27.695	44.786

The formula of total greenhouse gas emissions from coal transportation is as follows:

$$E=\sum_i \sum_j A_i * EF_{ij} * GWP_{ij} \quad (3)$$

In the formula, E is greenhouse gases emissions of coal, A_i is the activity level of i-th coal (t) ; EF_{ij} is the I-th coal's emission factor of i-th greenhouse gas(t/t); GWP_{ij} is the I-th coal's global warming potential of i-th greenhouse gas(t/t).

Table 6 The greenhouse gas emissions from the coal consumption $(10000tCO_2)$

	Calculation	Minimum	Maximum
CO_2 emissions	951467.08	884349.76	1023140.33
CH_4 emissions	205.24	190.65	220.12
N_2O emissions	403022.78	375227.33	434125.40
Total emissions	1356723.59	1266139.84	1442211.43

Simulating 4000 times by using Crystal Ball software, we could get the greenhouse gases emissions from the coal consumption. The results are shown in Table 6.

3.4 Total carbon emissions of the coal industry

Total GHG emission of coal lifecycle is equivalent with the sum emissions of coal mining, transportation and consumption as shown in Figure 1.

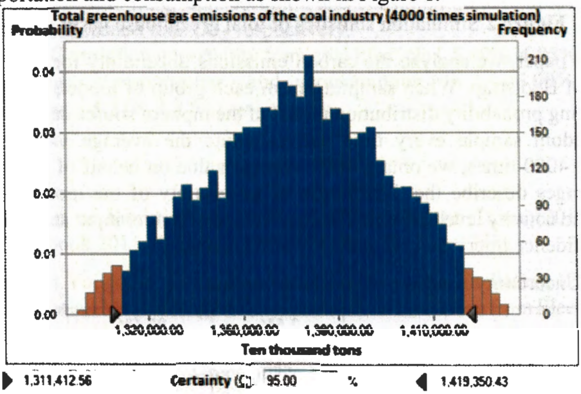

Figure. 1 Analog frequency view of total greenhouse gases emissions

It can be seen from Figure 2, total emissions of greenhouse gases from the coal industry in China is 13,671,867,200 tons in the year 2011, the 95% confidence interval is (1,297,537.98, 1,433,468.58).

4. Uncertainty analysis

Uncertainty estimate is an essential element of a complete emissions inventory. In the compile process, there are many uncertain factors in the estimation factors and activity levels, it can help to determine the direction of future efforts and guide decisions on methodological choice by uncertainty analysis. The "*National Greenhouse Gas Inventories Good Practice Guidance and Uncertainty Management*" formulated by the IPCC had united the methods of uncertainty quantification for each country. This section will analyze the uncertainty of China's coal emissions inventory in 2011.

[redacted]	Pred[redacted]ve value
Number of trials	5,000
Basic information	1,368,578.61
Mean	1,367,186.72
Median	1,367,834.03
Mode	—
Standard deviation	28,433.13
Variance	808,442,999.89
Skewness	-0.0806
Kurtosis	2.39
Coefficient of variation	0.0208
Min	1,297,537.98
Max	1,433,468.58
Average standard deviation	402.11

Figure 2 Simulation statistics of total greenhouse gases emissions

In this paper, we analyze the carbon emissions uncertainty for each source by the method of Bootstrap. When sampling from each group of model, sample distribution representing probability distribution model of the input of source category. We pick out 4000 random sample every time and calculate the average value. Therefore, by repeating 4000 times, we obtain 4000 average value on behalf of the input of model. The averages describe the distribution of uncertainty of the model input (emission factors and activity levels). Table 7 is the average of model input and the uncertainty of 95% confidence interval.

Table 7 Uncertainty Analysis of carbon emissions

Stages	Type	Averages (10,000 t CO_2)	2.5% Quantile (10,000 tCO_2)	97.5% Quantile (10,000 tCO_2)	Uncertainty (%)
Coal mining	CH_4	8526.67	4783.05	12502.50	(-43.90, 46.63)
	Total	8526.67	4783.05	12502.50	(-43.90, 46.63)
Coal transport-ation	CO_2	3142.88	2989.98	3300.88	(-4.87,5.03)
	CH_4	5.28	2.55	8.10	(-51.72,53.18)
	N_2O	168.25	69.17	297.38	(-58.89,76.75)
	Total	3328.35	3096.73	3574.06	(-6.96,7.38)
Coal consum-ption	CO_2	951467.08	899598.69	1007308.23	(-5.45,5.87)
	CH_4	205.24	193.92	216.80	(-5.52,5.63)
	N_2O	403022.78	381611.06	427324.76	(-5.31,6.03)
	Total	1356723.59	1286040.00	1422731.59	(-5.21,4.87)
Total emissions		1367186.72	1297537.98	1433468.58	(-5.09,4.85)

From the Table 7, we can see that the greenhouse gases inventory of coal mining has large uncertainty, Its' absolute value is greater than 40%,the main reason is the emission factor entered and activity emissions have large uncertainty, which spread to the total emissions of mining areas, it leads to the uncertainty of greenhouse emission is too large.

The uncertainty of CH_4 and N_2O from coal transportation is large, however the emissions uncertainty of greenhouse gases from coal transportation is low, it mainly due to the emission of CH_4 and N_2O is small, which has less impact on total uncertainty.

From the calculation, the total uncertainty of GHG emission inventory form coal lifecycle in China is (-5.09%, 4.85%) in 2011, which indicates the inventory can reflect GHG emissions from coal lifecycle accurately in 2011.

5. Conclusions

In the paper, we calculate the GHG emission inventory from coal lifecycle which includes coal mining, transportation and consumption in 2011 by using technique of Monte Carlo. The main conclusions are as follows:

1) The total GHG emission from the coal lifecycle in 2011is 1367186.72 ten thousand tons CO_2, of which, coal mining, transportation and consumption is 8526.67, 3328.35 and 1356723.59 ten thousand tons CO_2 respectively.

2) The range of GHG emission uncertainty from coal lifecycle (-5.09%, 4.85%) in 2011. The coal mining, transportation and consumption is (-43.90%,46.63%), (-6.96%,7.38%) and (-5.21%,4.87%) respectively.

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