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Environmental impact of coal mine methane emissions and responding strategies in China

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ABSTRACT

The impact on global climate change from coal mine methane emissions in China has been drawing attention as coal production has powered its economic development. Data on coal mine methane emissions from the State Administration of Coal Mine Safety of China has been analyzed. It is estimated that the methane emission from coal mining in China reached 20 billions of cubic meters in 2008, most of which comes from state-owned coal mines with high-gas content. China releases six times as much of methane from coal mines as compared to the United States. However, Chinese methane emission from coal production accounts for only a very small proportion on the environmental impact when compared to emissions of carbon dioxide from fossil fuel consumption. The Chinese government has shown environmental awareness and resolution on the mitigation and utilization of coal mine methane emissions. Measures have been taken to implement the programs of mitigation and utilization of coal mine methane, and at the same time, to ensure mining safety. Nearly 7.2 billions of cubic meters of methane were drained from the coal mines, and 32% of it was utilized in 2008. The slow advancement of technologies for the drainage and utilization of low-concentration methane from ventilation air hinders the progress of mitigation of atmospheric methane and the utilization of coal mine methane emissions.

1. Introduction

Radiative forcing (RF), the stratospherically adjusted radiative flux change evaluated at the tropopause, is usually used when climate impact is evaluated for different greenhouse gases (Forster et al., 2007). After carbon dioxide, methane has the second greatest radiative forcing among the long-lived greenhouse gases. It accounts for 14.3% of the global anthropogenic greenhouse gas emissions (Olivier et al., 2005, 2006; Rogner et al., 2007). In the past 20 years, amount of methane in the atmosphere has not shown any significant increase while its emission growth rate has decreased (Dlugokencky et al., 1998, 2003; Simpson et al., 2002). The latest valid data for methane in the atmosphere gives a concentration of 1775 ppb and a RF of 0.48 W/m^2 (Forster et al., 2007), as stated in the fourth climate change report of the Intergovernmental Panel on Climate Change (IPCC) in 2007.

Global warming potential (GWP) is a relative scale that compares one greenhouse gas in question to that of the same mass of carbon dioxide (whose GWP is by convention equal to 1) on the contribution to global warming. The RF caused by stratospheric water vapor has increased significantly since the third climate change report of the IPCC in 2001. Based on further analyses of the radiative balance change (Forster and Shine, 1999, 2002; Oinas et al., 2001; Shindell, 2001; Smith et al., 2001), the 100-year GWP for methane has increased from 23 (used in the third climate change report) to 25 (used in the fourth climate change report) (Forster et al., 2007).

Atmospheric methane originates from both non-biogenic and biogenic sources. More than 70% of the global total emissions come from biogenic sources which include wetlands, rice agriculture, livestock, landfills, forests, oceans and termites. Non-biogenic methane includes emissions from fossil fuel mining and burning, biomass burning, waste treatment and geological sources. Methane sources can also be divided into anthropogenic and natural. Anthropogenic sources include rice agriculture, livestock, landfills and waste treatment, biomass burning, and fossil fuel combustion. Natural methane is emitted from sources such as wetlands, oceans, forests, fire, termites and geological sources (Denman et al., 2007; Prather et al., 2001). Data from IPCC reveals that the estimated emission of methane is 582 Tg (Denman et al., 2007; Prather et al., 2001). Forty-eight percent is contributed by anthropogenic sources (based on the data of the total greenhouse gas emission released by IPCC (Rogner et al., 2007) and a GWP of 25 for methane).

Coal mining contributes a small portion of methane emissions among the various anthropogenic sources. Methane is usually the dominant species of gas released in coal mining. Coal mine methane (CMM) emissions are projected to increase through 2020 (IPCC, 2007; Methane to Market Partnership, 2008; U.S. EPA, 2006), with estimates as high as 793 MtCO_2e by 2020 (ESMAP, 2007). Estimates

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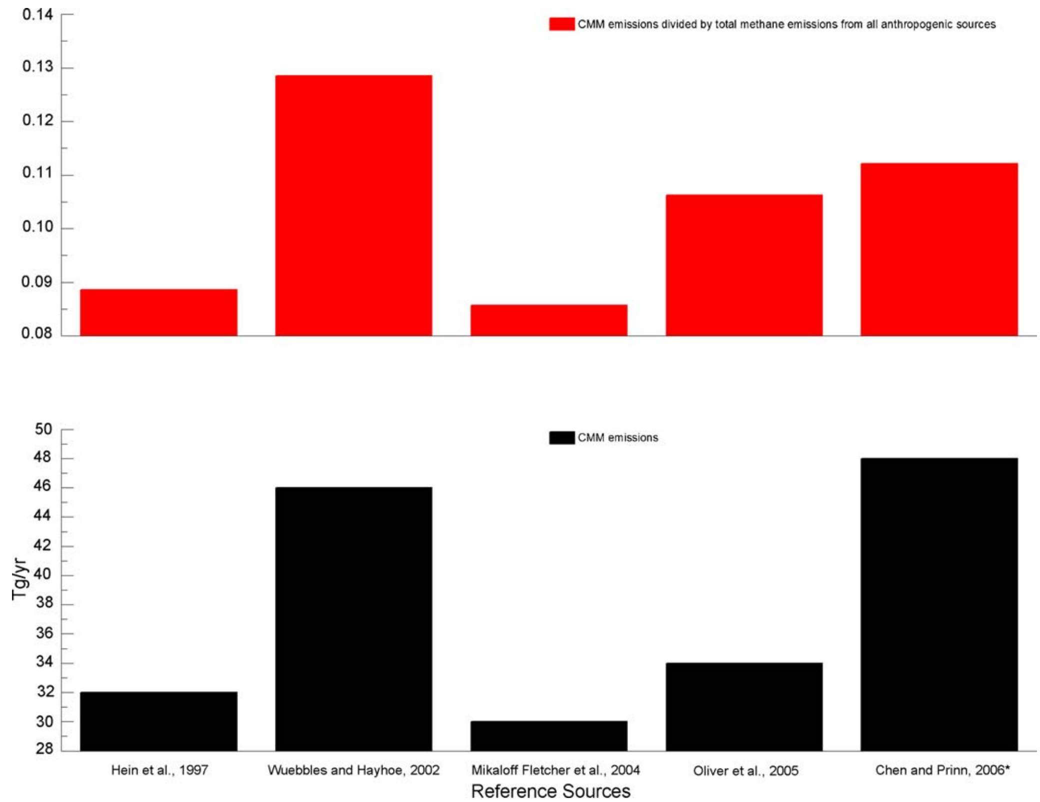

Fig. 1. Global CMM emissions compared with all anthropogenic sources (*Note*: *Including natural gas emissions.).

of CMM emissions show that global emissions of CMM account for 8.9–12.8% of the total anthropogenic sources (Denman et al., 2007). The detailed results are shown in Fig. 1.

Methane emissions involved with the process of coal mining include several sources (U.S. EPA, 2008):

- Degasification systems at underground coal mines (also commonly referred to as drainage systems).
- Ventilation air from underground mines, which contains dilute concentrations of methane.
- Abandoned or closed mines, from which methane may seep out through vent holes or through fissures or cracks in the ground.
- Surface mines, from which methane in the coal seams is directly exposed to the atmosphere.
- Fugitive emissions from post-mining operations, in which coal continues to emit methane as it is stored in piles and transported.

The first two sources, drainage and ventilation, account for the majority of the CMM emissions. About 85–90% of the total CMM emissions in China comes from underground coal mines, and ventilation air methane (VAM) is the major contributor (U.S. EPA, 2003). Thus, only methane emissions from coal mining work, i.e., VAM and drainage methane are studied in this paper.

China, with its fast-paced economic development, has the second largest energy consumption in the world. Accounting for 70% of the primary energy supply, coal plays a significant role on meeting China's energy demand. Coal production rose with an average annual increasing rate of 10% from 1299 Mt in 2000 to 3050 Mt in 2009 (BP plc, 2010). Under current policies, China's primary energy demand is projected to be over 3800 million tonnes of oil equivalent in 2030 (IEA, 2007). A large amount of underground methane has and will be liberated along with this rapidly increasing coal production in China. Not only is China the largest coal producer in the world; it is unique in that underground mines produce over 95% of the nation's coal. Because of the great depth and high rank of China's coals, the underground coal mines have higher methane emissions than surface mines. As the leading emitter of coal mine methane (Bibler et al., 1998), China has been drawing close attention on the environmental impact from CMM emissions.

Coal mine methane recovery and its utilization were developed in China in the early 1990s as a strategy to enhance coal mine safety, diversify energy resources and make use of a fuel. The government enacted a series of economic and administrative policies designed to encourage CMM utilization and greenhouse gas mitigation through CMM recovery. While programs on CMM recovery and utilization have been growing rapidly in recently years, a number of technical, economic and institutional barriers emerged during its implementation (IEA, 2009).

The objective of this paper is to evaluate the environmental impact from methane emissions of Chinese coal mines, and to give a diagnosis of the regulatory work on mitigation and utilization of CMM methane.

2. CMM emissions in China

Chinese safety code *Specification for identification of classification of gassy mines* (State Administration of Work Safety of China, 2006) requires all coal mines in China to be classified on gas hazard. The classification categories based on the gas emission rate are listed as: (1) slightly gassy mines, (2) highly gassy mines, and (3) very gassy mines (coal/rock and gas outburst-prone mines). State Administration of Coal Mine Safety of China has published reports on the classification of all working coal mines in China for the year of 2007 and 2008. The reports give a "gassy" identification label to 15,071 coal mines in 2007, and 12,722 in 2008 for 26 provinces/autonomous regions/municipalities. According to the ownership of different coal mines, the results were rendered within three categories: (1) centrally administrated state-owned mines,

Table 1
CMM emission estimates in China in 2007–2008.

Year	Total emission		Emission from highly gassy and outburst-prone mines		Emission from slightly gassy mines	
	Unit in Tg	Unit in billions of cubic meter	Unit in Tg	Unit in billions of cubic meter	Unit in Tg	Unit in billions of cubic meter
2007	13.8	19.3	10.4	14.5	3.4	4.8
2008	14.5	20.2	10.9	15.2	3.6	5

Notes:
1. Density of methane is taken as 0.716 kg/m^3, a density in standard condition, when the volumetric raw data is converted into gravimetric units. Some numbers may not match when summed up due to the roundup error.
2. 1 Tg = 10^6 t.
3. The results may be over-estimated as some mines discharge the drainage methane from portable drainage pumps, which causes duplicate add-up.
4. Methane that has been utilized is not subtracted from the total emissions.

(2) local state-owned mines, and (3) collective & private mines. For each coal mine, the report gives the maximum gas emission rate in 30 consecutive days (including methane/CO_2 from ventilation and drainage respectively). The total annual CMM emission of these coal mines then was estimated from of the data of every working coal mine.

Based on the reports (State Administration of Coal Mine Safety of China, 2008b, 2009), the total CMM emission in China is estimated to be 13.8 Tg (19.3 billions of cubic meters) in 2007. The emissions from centrally administrated state-owned mines, local state-owned mines and collective & private mines are 6.6 Tg (9.2 billions of cubic meters), 2.2 Tg (3.1 billions of cubic meters) and 5 Tg (7 billions of cubic meters), respectively. A similar analysis was done for the year of 2008. However, data for slightly gassy mines was not available. It was estimated by employing the 2007 emission proportions for the different gassy categories. The detailed estimations are shown in Table 1.

Fig. 2 gives the emission estimates on a regional basis for the year of 2007. Regions of high methane emissions correspond with those of high coal production, which include Shanxi, Guizhou, Henan, Sichuan, Chongqing, and Anhui. The first four regions above account for the 59% of the total national-wide methane emissions. It is interesting to compare the CMM emissions to the coal production (as shown in Fig. 3) for these different regions. Most of the regions show a reasonable correlation between CMM emissions and coal production, except for regions like Neimenggu, Guizhou, Chongqing, and Shaanxi. The discrepancy represents typical complicated conditions on coal reserve and gas content over the vast area of China. The CMM emission depends not just on the coal production, but also the methane content in the coal seams and drainage conditions of the gas.

The CMM emission is distributed over the mine ownership in 2007 as 48%, 16% and 36% for centrally administrated state-owned mines, local state-owned mines and collective & private mines, respectively. By contrast, the proportions of coal production for these three ownership categories are 49%, 13% and 38%, respectively. This gives a reasonable relationship between coal production and methane emissions, as one would expect them to correlate. The small discrepancies can be attributed to different methane concentrations over the main coal production regions and varied feasibilities on implementing the administrative policies of CMM recovery and utilization over different coal mine ownerships. Due to a concern of safety, a concentration of below 30% of methane in the drainage system is not advised, which may result in

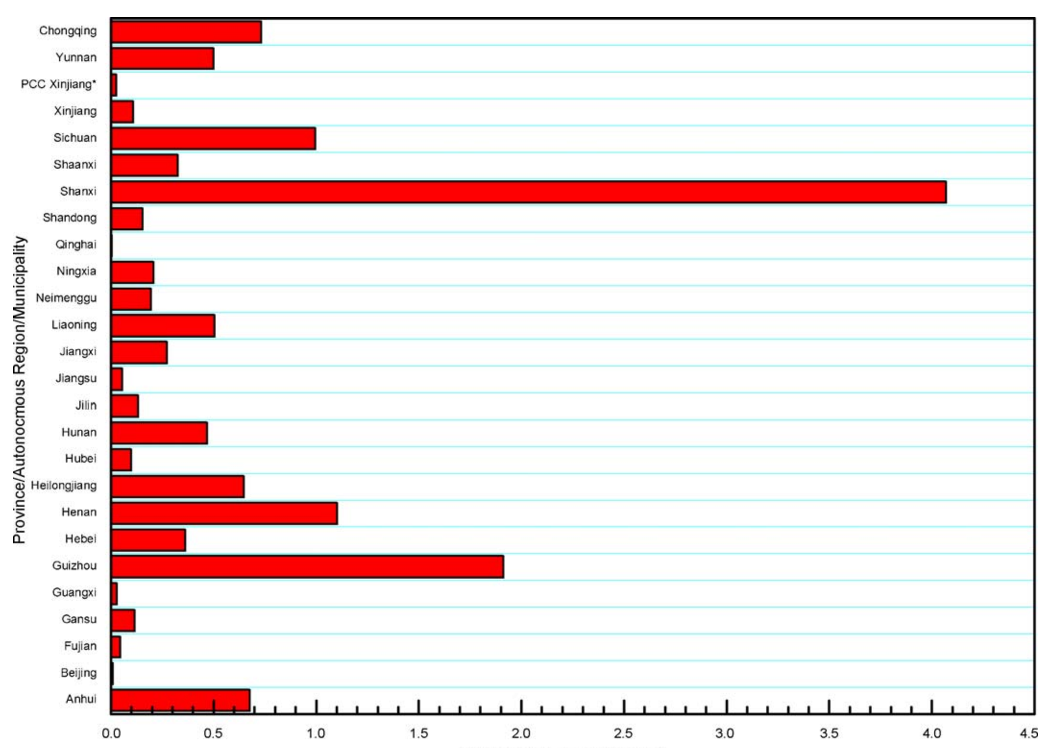

Fig. 2. CMM emissions from 26 regions in China in 2007 (*Note*: *Production and Construction Corps of Xinjiang.).

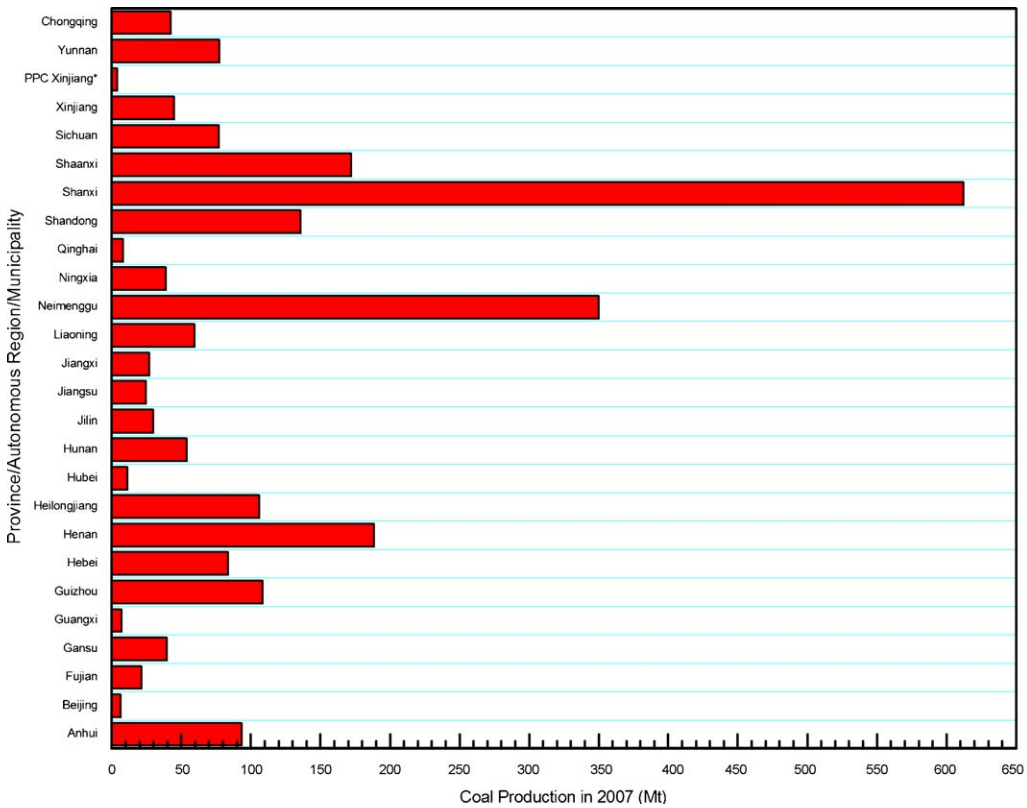

Fig. 3. Coal productions from 26 regions in China in 2007 (*Note*: *Production and Construction Corps of Xinjiang. Data source: State Administration of Coal Mine Safety of China, 2008a.).

a greater discrepancy between coal production and methane emission. Weak feasibilities of policy implementation include: a lack of information and expertise at the local level about CMM power generation; ineffective subsidies for CMM electricity generation; a lack of degasification technologies suitable for the specific coal seams; a lack of markets to use the recovered methane.

If compared by gassy classification of coal mines, the "highly gassy" classification mines and outburst-prone mines account for about three quarters of the total CMM emissions. This is due to the rich gas content in these mines.

Fig. 4 gives the CMM emission estimates from highly gassy mines and outburst-prone mines for the 26 regions with coal production in 2008. Proportions for different regions show similar trends compared with Fig. 2. More detailed comparison on the emission estimates from highly gassy mines and outburst-prone mines for the two years is shown in Fig. 5. There is an increase in emission compared to 2007, but the proportions of emission for different regions in 2008 are similar to 2007. Increased coal production is responsible for the increase in emissions. Upgrading of some slightly gassy mines to highly gassy mines and outburst-prone mines, which is due to deeper mining level and more complex mining conditions, can also result in the increase of total CMM emissions.

Proportions of CMM emissions divided by ownership of highly gassy mines and outburst-prone mines in 2008 are 63%, 14% and 23% for centrally administrated state-owned mines, local state-owned mines and collective & private mines, respectively. The comparison of absolute emissions amount with those in 2007 is shown in Fig. 6. It shows that both the proportion and absolute emissions amount render an increasing trend for centrally administrated state-owned mines and local state-owned mines, which is possibly due to the closure of some small collective & private mines and merger into state-owned mines enforced by the government.

3. Contribution of CMM emissions to greenhouse gases in China

Carbon dioxide is the dominant greenhouse gas, accounting for 76.7% of the total anthropogenic greenhouse gases with 74% originating from the consumption of fossil fuel. Annual coal production and carbon dioxide emissions from the consumption of fossil fuel, along with their proportions among the world, are shown in Fig. 7 (BP plc, 2010). Fig. 7 indicates increasing trends on both coal production and CO_2 emissions for China over the past decade. While China's coal production over the world is 44%, its contribution to CO_2 emissions from fossil fuel consumption only takes 24% of the total emissions worldwide for 2009. However, the slope of the increasing trend of CO_2 emissions is steeper, compared with coal production.

CMM emissions (in CO_2 equivalent) and its ratio with CO_2 emissions from fossil fuel consumption for U.S. and China in 2007–2008 are listed in Table 2 (BP plc, 2010; State Administration of Coal Mine Safety of China, 2008b, 2009; U.S. EPA, 2010). The comparison shows that CO_2 emissions from fossil fuel consumption in China have overtaken those from U.S. in the past two years. However, due to the high reliance on coal for its energy demand, the CMM discharge for China is nearly six times of the US. However, the contribution to its total greenhouse gases from CMM emission in China is insignificant, if not negligible. The ratio of CMM emissions amount (CO_2 equivalent) over the CO_2 emissions amount from fossil fuel consumption is merely 0.05. So CO_2 is by far the dominant contributor to greenhouse gases.

From the discussion above, one can conclude that even though methane carries a GWP over CO_2 of 25 times, CMM emissions play an insignificant role in contributing to the global greenhouse gases as fossil fuel consumption accounts for a dominant source for greenhouse gases.

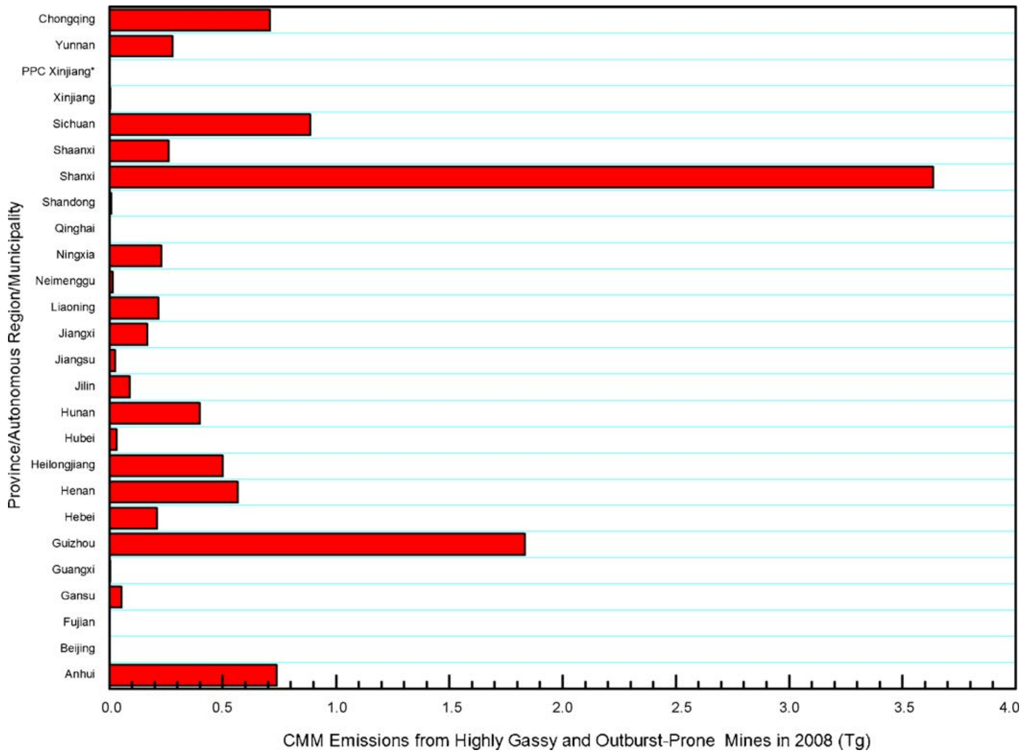

Fig. 4. CMM emissions from highly gassy mines and outburst-prone mines for 26 regions in China in 2008 (*Note*: *Production and Construction Corps of Xinjiang.).

4. Mitigation and utilization of CMM in China

Despite the fact that CMM emissions in China account for little of the greenhouse gases, the total emissions amount is still large. Hence its environmental impact encourages us to mitigate and utilize the CMM. CO_2 is one of the final species released when methane is utilized, yet with a much lesser impact to the environment as compared to the direct emission of methane. Reduced CO_2-equivalent emission (A) for flaring of every cubic meter of methane could be calculated from the oxidation reaction for methane below:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

$$A = \left(GWP_{CH_4} - CEF_{CH_4}\right)\rho_{CH_4} \quad (1)$$

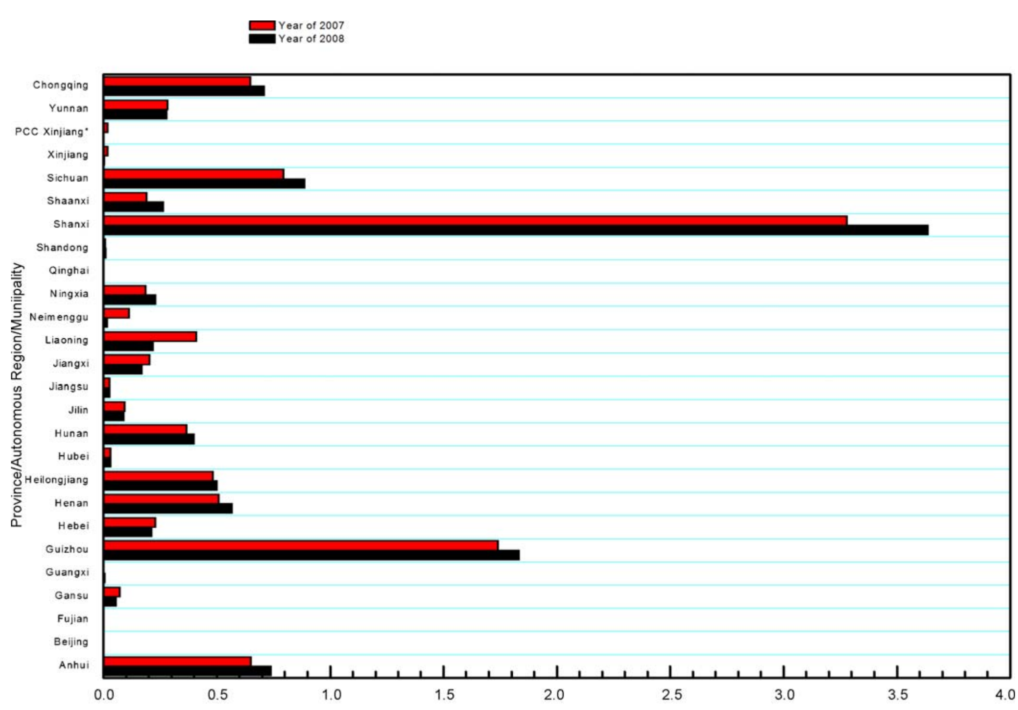

Fig. 5. Comparison of CMM emissions from highly gassy mines and outburst-prone mines for 26 regions in China in 2007–2008 (*Note*: *Production and Construction Corps of Xinjiang.).

Table 2
CMM emissions amount (CO_2 equivalent) and the ratio of it over CO_2 emissions amount from fossil fuel consumption for U.S. and China in 2007–2008.

Year	U.S.			China		
	CMM (Tg CO_2 Eq.)	CO_2 from FFC[a] (Tg)	CMM/CO_2 from FFC[a]	CMM (Tg CO_2 Eq.)	CO_2 from FFC[a] (Tg)	CMM/CO_2 from FFC[a]
2007	58.1	6,565.3	0.009	344	6,468.0	0.053
2008	67.3	6,369.1	0.010	361	6,907.9	0.052

Notes:
1. Data of CO_2 emissions come from the BP report (BP plc, 2010), and methane emissions for U.S. and China from gassy identification reports (State Administration of Coal Mine Safety of China, 2008b, 2009) and report of Environment Protection Agency of United States (U.S. EPA, 2010), respectively.
2. A GWP of 25 is used for methane when converting the methane emission to its CO_2-equivalent amount.
[a] Fossil fuel consumption.

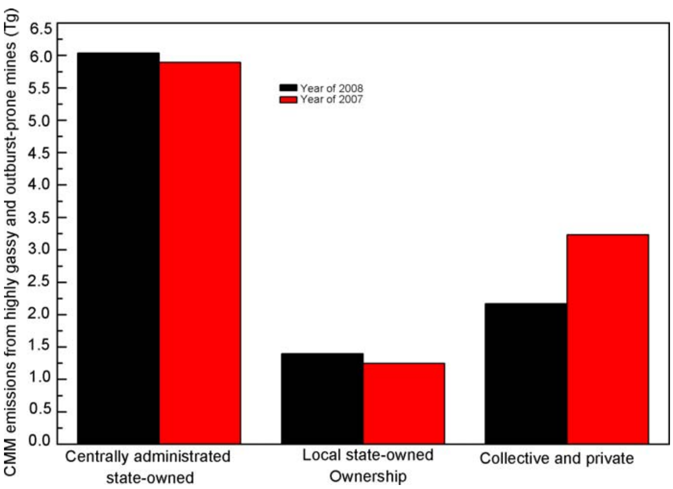

Fig. 6. Comparison of CMM emissions on an ownership basis for Chinese coal mines in 2007–2008.

where ρ_{CH_4} is the density of methane for standard condition, 0.716 kg/m^3; GWP_{CH_4} is the global warming potential for methane, 25 is taken based on the fourth climate change report of IPCC; CEF_{CH_4} is the mass of CO_2 released per unit mass of methane from the oxidation reaction, 2.75 (from the stoichiometric ratio of 44/16); A is the reduced CO_2-equivalent emission (mass) per unit volume of methane, kg/m^3.

Based on Eq. (1) it can be calculated that the flaring of every cubic meter of methane would reduce 15.9 kg of CO_2-equivalent emission.

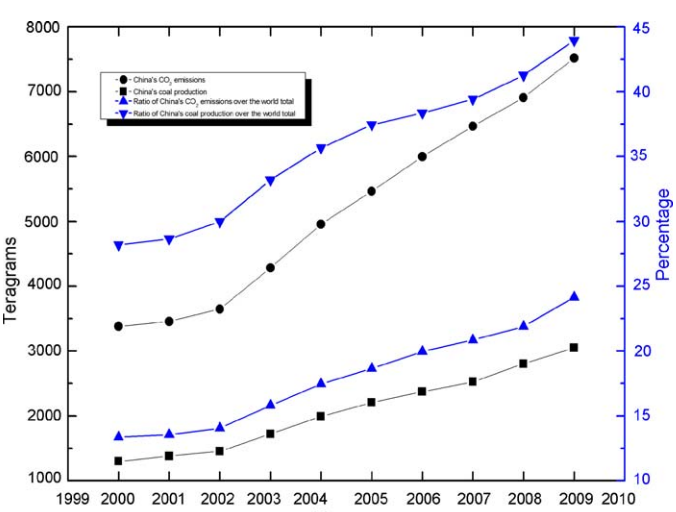

Fig. 7. Coal production and carbon dioxide emissions from the consumption of fossil fuel in China and their proportions among the world in 2000–2009.

The coal industry in China has been actively involved with international cooperative projects for the promotion and the utilization of methane and its mitigation of greenhouse gases. These practices follow the prescriptions of government's code: *Administrative Provisions on Projects of Clean Development Mechanism*. Gas-based power generation is the dominant project type of methane utilization. Coal industries which are involved with Clean Development Mechanism (CDM) projects and have achieved methane utilization include Huainan Mining Group, Tiefa Mining Group, Songzao Coal & Electricity Group, Jincheng Mining Group, Yangquan Mining Group, etc. These companies acquire methane utilization technology, and get compensation from the CDM projects. This methane utilization not only promotes methane drainage, but also plays a leading role on ensuring the coal mine safety.

4.1. Drainage of CMM in China

According to China's 11th Five-Year Plan (2006–2010), the objectives regarding CMM drainage and utilization are as follows by the end of 2010:

(1) The drainage amount of CMM will reach 5 billions of cubic meters with a drainage efficiency (the proportion of methane (by volume) captured in a methane drainage system relative to the total quantity of gas liberated) of greater than 40%.
(2) The methane amount initialized will reach 3 billions of cubic meters with a utilization efficiency (the proportion of methane (by volume) utilized relative to the total quantity of gas drained) of greater than 60%.

Up to now, this objective has been partially achieved. The actual amounts for CMM drainage and utilization in China for 2004–2009 are shown in Fig. 8. It can be seen from Fig. 8 that the methane

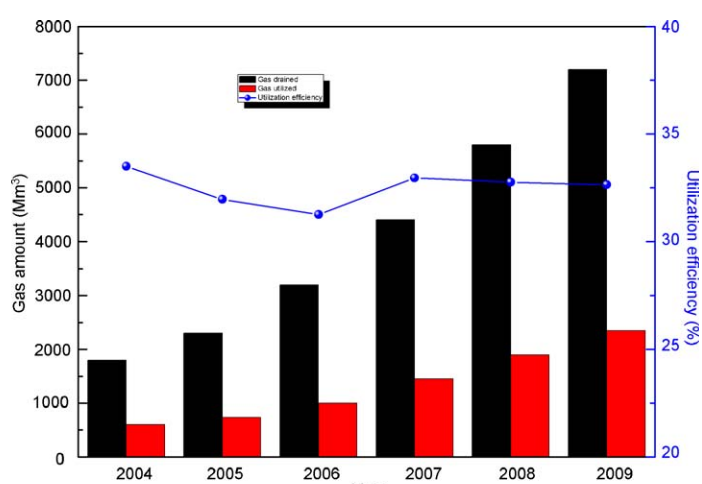

Fig. 8. Drainage and utilization of CMM in China in 2004–2009.

Table 3
CMM drainage and utilization amounts from underground and surface of the mines in China in 2008–2009.

Year	Drainage (millions of cubic meters)		Utilization (millions of cubic meters)	
	From underground	From surface	From underground	From surface
2008	5300	500	1600	301
2009	6170	1013	1770	582

drainage amount has increased dramatically over the years and the number comes to 7.2 billions of cubic meters in 2009, which surpasses the objective set in the 11th Five-Year Plan. On the other hand, the amount for utilized methane has not shown a significant increase over the past years. This results in a relatively stable utilization efficiency of about 32%. Thus this is still short of the objective of 60% set in the 11th Five-Year Plan.

Among the major coal production regions, provinces with great scale of methane drainage include Shanxi, Liaoning, Anhui, Henan, Chongqing, Sichuan, Guizhou, Shaanxi, Ningxia, etc. Annual methane drainage amounts for many coal production companies, such as Yangquan, Jincheng, Huainan, Fushun, Huaibei, Shuicheng, Panjiang, and Songzao, have surpassed 100 millions of cubic meters. Provinces such as Shanxi, Liaoning, Anhui, Chongqing, and Guizhou have drained more than 200 millions of cubic meters of CMM per year.

The detailed data for CMM drainage and utilization amounts from underground and surface of the mines for the most recent two years are listed in Table 3.

The most common forms of methane utilization are involved with power generation, industrial applications, motor vehicle fuel and other civil applications. Power-generating capacity in China from methane conversion has achieved 710 million watts since 2007. The largest methane conversion power-generating plant in the world, located in the Jincheng Coal Group, has combined to the grid with a capacity 120 million watts. Civil application of drained methane accounts for 70% of total methane utilization and has been deployed to more than 870,000 families.

From the geological view of methane drainage conditions, most China's coal took shape over a period of Carboniferous-Permian. After that the coal went through a number of strong tectonic movements that destroyed the original cracks in coal seams, and turned them to be soft, high-ranked, construction-complicated, and less smooth for the gas flow. Due to this particular geological condition, methane in Chinese coal seams is characterized by poor drainability, low drainage efficiency, and high maintenance. Coal seam permeability rates in most of Chinese mines, except for the Jincheng coal mine, are in the range of 10^{-4}–10^{-3} mD, which are four orders of magnitude lower than the U.S. and three orders of magnitude lower than Australia. The special condition of the Chinese coal seams directly leads to poor drainage results. The methane concentration for drainage gas in most Chinese coal mines is lower than 30% which is the minimum requirement (State Administration of Coal Mine Safety of China, 2005).

Despite of the difficulties discussed above, researchers and engineers have developed several drainage methods suitable for Chinese coal mines, i.e., drainage before mining, during mining and after mining. Specific design methods and technical parameters have been introduced for different drainage periods (Cheng et al., 2003, 2009; Cheng and Yu, 2007; Liu et al., 2009; Yu et al., 2004). The performance of methane drainage systems can also be significantly improved through a combination of proper installation and maintenance, regular monitoring, and systematic drilling.

4.2. Abatement of VAM in Chinese coal mines

For a long time, methane in ventilation air from coal mines has been emitted directly to the atmosphere without any utilization. This lack of utilization was due to its low concentration and the demanding technology needed (Ning and Chen, 2005; Yuan and Naruse, 1999). Data of 2007–2008 show that the amount of VAM discharged to the atmosphere every year in China was approximately 14.4–14.8 billions of cubic meters, accounting for the 71–77% of the whole CMM emissions.

The 135th clause of *Safety Code for Coal Mines* provides that the safe concentration of methane in main return airways or one-wing return airways should not exceed 0.75% (State Administration of Coal Mine Safety of China, 2005). This provision limits the methane in coal mine ventilation air to a relatively low level. Even highly gassy or outburst-prone classified coal mines have very low concentrations of methane in the ventilation system, as part of the CMM is released by the drainage system. Thus despite of the great amount of the VAM, the particularly low methane concentration, usually lower than 0.25%, sets back the utilization of the VAM.

As a typical representative case study, the emissions data of VAM and methane drainage in the Huaibei coal production group and the Huainan coal production group are listed in Tables 4 and 5.

It can be seen from Tables 4 and 5 that the methane concentrations in ventilation air for slightly gassy mines are generally low (less than 0.26%) while the amount of drainage methane is barely noticeable. Even for highly gassy and outburst-prone mines, the methane concentration is still relatively low: a maximum value of 0.66% and average value of 0.36% for mines in Huaibei; and a maximum value of 0.28% and average value of 0.15% for mines in Huainan. This situation would certainly present difficulties for the utilization of the VAM since most VAM utilization technologies require a 0.5% methane concentration as the minimum concentration for stable working.

It is difficult to perform large-scale VAM utilization programs in China as most of the coal mines are located in rural mountain areas with less industrial demand due to small population and less-developed economy. At this time, VAM-derived power generation is not commercially feasible without carbon revenues or other incentives, such as preferential electricity pricing or portfolio standards (United Nations ECE and Methane to Market Partnership, 2010).

Methane oxidation is a general method for VAM utilization. Methane is usually used as a primary or auxiliary fuel when being oxidized. Example of methane as an auxiliary fuel is to replace air for gas turbines and internal combustion engines close to coal mines with ventilation air containing low-concentration methane (Su and Agnew, 2006). This method is constrained by the engine locations, and subject to conditions of lean-burning. Techniques for the application of methane as a primary fuel include thermal flow-reversal reactors (TFRR) (Kosmack, 2003; Kosmack et al., 2007; Mattus, 2004, 2007, 2008a, b), catalytic flow-reversal reactor (CFRR) (Carothers and Deo, 2000a,b; Hristo and Gilles, 2004; Sapoundjie, 2005; Su and Agnew, 2006), and other technologies (Yang et al., 2008). VOCSIDIZER, developed by MEGTEC, is a typical TFRR equipment and has been applied in several programs around the world. Difficulties with its application in China involve high installation and maintenance costs, and on the local production of raw materials. However, field tests with TFRR technologies have been conducted in Wangying mine of Fuxin Coal Production Group and Binchang mine in Shaanxi province. The physical chemistry institute within the China Academy of Science in Dalian has

Table 4
CMM emissions of mines in Huaibei coal production group.

Mines	Rank of gas content	Concentration of VAM (%)	Ventilation air volume (m^3/min)	VAM amount (m^3/min)	Amount of methane drainage (m^3/min)
Yuanzhuang	Highly gassy	0.36	5,461	19.7	0
Shuanglong	Slightly gassy	0.26	8,008	20.8	0
Zhuzhuang	Highly gassy	0.52	6,855	35.6	0
Daihe	Highly gassy	0.64	5,194	33.2	0
Yangzhuang	Highly gassy	0.66	9,502	62.7	0
Luling	Outburst-prone	0.4	21,875	87.5	49.2
Suli	Highly gassy	0.5	9,908	49.5	0
Shitai	Outburst-prone	0.39	7,413	28.9	0
Zhuxianzhuang	Outburst-prone	0.4	9,995	40.0	7.9
Linhuan	Highly gassy	0.38	13,313	50.6	0
Haizi	Outburst-prone	0.24	15,023	36.1	35.5
Tongting	Outburst-prone	0.25	7,904	19.8	0
Taoyuan	Outburst-prone	0.22	11,255	24.8	11.2
Qinan	Outburst-prone	0.35	12,823	44.9	25.8
Xutuan	Highly gassy	0.38	16,045	61.0	6.3
Guobei	Slightly gassy	0.07	8,500	6.0	1.8
Suntuan	Slightly gassy	0.15	11,560	17.3	0

Notes:
1. Average value of methane concentration is taken if there is more than one airshaft.
2. Add-up value of ventilation volume is taken if there is more than one airshaft.

Table 5
CMM emissions of mines in Huainan coal production group.

Mines	Rank of gas content	Concentration of VAM (%)	Ventilation air volume (m^3/min)	VAM amount (m^3/min)	Amount of methane drainage (m^3/min)
Xinzhuangzi	Outburst-prone	0.28	30,267	84.7	135.4
Xieyi	Outburst-prone	0.17	36,803	62.6	93.9
Panyi	Outburst-prone	0.28	31,515	88.2	114.3
Paner	Outburst-prone	0.12	19,703	23.6	20.1
Pansan	Outburst-prone	0.25	24,519	61.3	78.7
Xieqiao	Outburst-prone	0.07	41,285	28.9	23.0
Zhangji	Outburst-prone	0.08	60,190	48.2	88.0
Liyi	Outburst-prone	0.10	8,901	8.9	1.6
Lizuizi	Outburst-prone	0.08	16,587	13.3	6.1
Panbei	Highly gassy	0.06	16,967	10.2	6.0
Gubei	Outburst-prone	0.06	24,954	15.0	4.7
Guqiao	Highly gassy	0.25	38,134	95.3	72.9
Dingji	Outburst-prone	0.21	27,073	56.9	103.5

Notes:
1. Average value of methane concentration is taken if there is more than one airshaft.
2. Add-up value of ventilation volume is taken if there is more than one airshaft.

developed CFRR technology equipment that has reached a working capacity of 1000 m^3/h.

4.3. Regulatory approaches of Chinese government on mitigation and utilization of CMM

Gas is responsible for most of the coal mines accidents in China. Casualties from gas-related accidents accounts for 51.2% of the large accidents (3–9 fatalities) and 80.3% of extremely large accidents (more than 10 fatalities), according to 2007 coal mine accident statistics. Chinese coal mine gas accidents can be classified into gas explosions, coal and gas outbursts, gas combustion and asphyxiation due to high-gas concentration. So coal mine gas is not only intense greenhouse gas, but poses a safety hazard. Alternatively with proper techniques and management coal mine gas could turn into clean and high-efficiency fuel. Therefore, the control of coal mine gas could eliminate safety risks in coal production, and also provide high-efficiency and clean energy while reducing greenhouse gas emissions.

Utilization of coal mine gas (methane) is the core objective of the Chinese government's policies on coal mine gas control. Such control promotes gas extraction, thus ensuring mining safety, and at the same time, reduces greenhouse gas emissions.

Over the past years, several departments of the Chinese central government have been supportive of the coal mine gas industry by issuing a series of regulations. These regulations provide the guidelines on the mitigation and utilization of CMM emissions, set objectives of the coal gas control on coal mine production companies, and prescribe prices, taxation and compensation. These regulations include:

- *Administrative provisions on adjustment and supervision of coal production safety fees.* Issued on April 8, 2005.
- *Overall program of coal mine gas control and utilization.* Issued on June 22, 2005.
- *Implementation recommendations of coal mine gas control and utilization.* Issued on June 24, 2005.
- *Administrative procedures on prices and cost-sharing of renewable energy.* Issued on January 4, 2006.
- *Plans on exploitation of the coal mine gas (methane).* Issued on June 12, 2006.
- *Recommendations on accelerating the coal mine gas control and utilization.* Issued on June 15, 2006.
- *Taxation provisions on exploitation of coal mine gas.* Issued on February 7, 2007.

- *Implementation recommendations of power generation by use of the coal mine gas (methane).* Issued on April 2, 2007.
- *Administrative provisions on prices of the coal mine gas.* Issued on April 20, 2007.
- *Implementation recommendations of compensation on exploitation of the coal mine gas (methane).* Issued on April 20, 2007.

Despite the difficulties with utilization technologies for low-concentration methane and other constraints, the Chinese government has shown great resolution on the mitigation and utilization of CMM emissions. However, regulatory approaches regarding taxation and compensation are not working as good leverages. Future progress on the mitigation and utilization of CMM must rely on the technical development of drainage and utilization of low-concentration methane. Through continuing improvement and applications of these technologies, more CMM will be exploited, thus moves forward to the objective of greenhouse gas mitigation.

5. Conclusions

As the second most important greenhouse gas, methane carries a GWP of 25 and poses substantial impact on global climate change. CMM emissions account for 8.9–12.8% among a series of anthropogenic methane emission sources. Dramatic increase in coal production for the past years in China has brought about concern with the environmental impact of CMM emissions. In 2007, CMM emissions in China reached 13.8 Tg (19.3 billions of cubic meters), most of which contributed by the state-owned mines with high-gas content.

Although the total amount of CMM emissions in China is great, about six times of that in the U.S., its contribution to global warming is relatively small, about 5%, when compared with CO_2 emitted from the fossil fuel consumption in China.

VAM accounts for 65–70% of the total CMM emissions in China as most of the coal mines are located underground. A case study of mines in the Huaibei and Huainan coal production groups shows that the methane concentration in coal mine ventilation air is generally low and does not meet the technical requirement of VAM utilization. In the work of methane drainage from coal mines, the geological characteristics of high rank and low permeability for Chinese coal seams result in poor drainability, low drainage efficiency and high maintenance.

The Chinese government has realized the possible environmental impact of CMM emissions and issued a number of administrative regulations regarding mitigation and utilization of CMM emissions. Price control, taxation and compensation have been used as means of guiding the mitigation and utilization programs. However, these leverages are not fully functional due to constraints from natural conditions and slow advancement in technologies. Further solutions would need improvement of technologies on drainage and exploitation of low-concentration methane.

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