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Energy Industry Methane Emissions Trajectory Analysis in China until 2050

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Abstract: Methane (CH_4) is an important greenhouse gas. There is increasing attention to CH_4 abatement strategies because of its contribution to short-term warming and strong benefits of decreasing CH_4 emissions. China greenhouse gas inventory methods are used to predict CH_4 emissions from the energy industry and to assess the potentials of CH_4 abatement policies and techniques by 2050. The NDC scenario results show using oil and gas as transitional clean energy sources instead of coal will increase CH_4 emissions from oil and gas industries at least 70%, but CH_4 emissions from the coal industry will decrease 45%, meaning total CH_4 emissions from the energy industry will continually decrease at least 30% in 2030 compared with 2020. Energy-related CH_4 emissions might peak around 2025, ahead of CO_2 emission peaking. CH_4 emissions will then decrease slightly and decrease markedly after 2030. Emissions in 2050 are expected to be 32% lower than emissions in 2020. In an extreme scenario, emissions may be 90% lower in 2050 than in 2020. It is suggested that the verification system for the energy industry's CH_4 emission accounting at the national level be improved and CH_4 control targets in line with national emission targets and the "14th Five-Year Plan" development stage be formulated.

Keywords: methane emission; greenhouse gas; 2050; scenario analysis; China

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1. Introduction

Positive global responses to climate change have been made since the Paris Agreement was signed, and low-carbon development has become a goal for all countries. The Emissions Gap Report 2020 indicated that the novel coronavirus (COVID-19) pandemic caused global carbon dioxide (CO_2) emissions to decrease. It has been estimated that total CO_2 emissions decreased by 7% in 2020 [1]. However, this decrease would only cause a 0.01 °C decrease in global warming by 2050. This falls very short of the Paris Agreement target. Nationally determined contributions (NDCs) agreed by all countries under the Paris Agreement are still seriously inadequate. Even if all unconditional NDCs are fully achieved, emissions predicted for 2030 indicate that 3.2 °C of warming would occur by the end of this century [1]. The global average surface temperature has so far increased by >1 °C, and more than the global average warming has occurred in China. If the temperature continues to increase at the current rate, 1.5 °C of global warming may have occurred between 2030 and 2052 [2]. Attention is increasingly being paid to decreasing methane (CH_4) emissions as part of the global response to climate change. CH_4 is the second-most important greenhouse gas (GHG), after CO_2. CH_4 makes large contributions to short-term warming, which will respond well to decreasing CH_4 emissions, so decreasing CH_4 emissions is attracting increasing attention from the international community. China and the US have issued a joint declaration at COP 26, in which it stressed the significant impact of methane emissions on global warming and agreed that more actions to control methane emissions are necessary in the 2020s and also pointed out specific work directions and plans. The cooperation on methane control is seen as moving from a scientific consensus to a political one.

The Fifth Assessment Report published by the Intergovernmental Panel on Climate Change (IPCC) indicated that the contribution of non-CO_2 GHGs to total GHG emissions has remained stable at 25% [3]. It has been predicted by many international agencies, including the United States Environmental Protection Agency (US EPA), that non-CO_2 GHG emissions will continue to increase in the future [4]. The global warming potentials of various non-CO_2 GHGs were updated and increased in the IPCC Fourth Assessment Report and Fifth Assessment Report [5]. This has increased the contributions of non-CO_2 GHG emissions to global climate change relative to the contributions found in earlier studies. It has been stated in numerous studies [6,7] that non-CO_2 GHG emissions will continue to grow if no controls are implemented and that this will offset the effects of efforts to decrease CO_2 emissions. The International Energy Agency has found that 570 million tons of CH_4 are emitted around the world each year [8], 40% from natural sources and the remaining 60% through human activities. The dominant sources of anthropogenic CH_4 are, in decreasing order, agriculture (24% of total emissions); the energy sector, which includes emissions from coal, oil, natural gas and biofuels (20%); waste disposal (11%); and biomass fuel production and combustion (6%).

International studies of CH_4 emissions have mainly been in several fields. Many studies have been focused on CH_4 emission patterns and the advantages of decreasing emissions. In most studies, decreasing CH_4 emissions has been found to be important to allow many countries to identify flexible solutions to achieving GHG emission targets [9–16]. Recently, some studies emphasize the importance of reducing short-lived climate pollutants (including non-CO_2 GHGs such as methane and some F-gases). They have also identified a significant potential for reducing non-CO_2 GHGs in China, but there are large uncertainties [17–21]. These uncertainties about non-CO_2 GHG emissions are due to the fact that the sources are contingent on the available production technologies and mitigation measures. Wang et al. [22] found that the uncertainties in China's inventories of non-CO_2 GHG range from a low of ±15% to a high of ±55%, with the greatest uncertainty related to N_2O and CH_4 emissions. In other studies, the costs and benefits of decreasing CH_4 emissions have been evaluated and analyzed. In most such studies, it was found that the costs of decreasing GHG emissions can be decreased to a remarkable degree by decreasing CH_4 emissions. Combining techniques for decreasing CO_2 and CH_4 emissions costs 20%–60% less than only using techniques for decreasing CO_2 emissions [23–25]. Decreasing CH_4 emissions will also markedly improve air quality [26–30], improve health [31,32], and prevent some negative effects of air pollution on crop yields. This will therefore improve national food supply security, decrease tropospheric ozone concentrations, and increase the carbon capture capacities of the biosphere at the regional level [33]. Some studies have been focused on evaluating and analyzing the effects of policies on decreases in CH_4 emissions. Voluntary partnerships were dominant in the early stages [34,35], but formal multilaterally supported projects to decrease CH_4 emissions have become dominant [36,37]. Various targets for decreasing CH_4 emissions have been established, indicating that efforts to control CH_4 emissions have accelerated [38–40].

In response to the growing global concern about the importance of methane emissions reduction, a series of studies have recently been carried out on methane emission accounting methods for Chinese coal mining [41,42]. These studies have provided a series of bottom-up perspectives on the methane emission factors and reduction potential of Chinese coal mines, providing a database to continuously reduce uncertainty in methane accounting. At the same time, as the global response to climate change progresses, the future trends of non-CO_2 GHG in China are attracting widespread attention. Research institutions have successively carried out quantitative analyses of energy-related methane emission pathways, i.e., including an assessment of the trends and potential of non-CO_2 GHG emissions in the medium and long term [17,43], as well as a comprehensive assessment of the contribution of non-CO_2 emissions reductions until 2030 [20].

CH_4 emission inventories and future scenario analyses are essential to establishing targets for decreasing CH_4 emissions and analyzing methods for decreasing CH_4 emissions.

Energy-related CH_4 emissions present great challenges in terms of developing methods to decrease emissions and the availabilities of emission factors. CH_4 emission data are much more uncertain than CO_2 emission data in national information bulletins and biennial updates. Anthropogenic CH_4 emissions in China in 2014 were 55 million tons [44], of which 25 million tons were caused by energy production. Energy-related CH_4 emissions in China are mainly related to coal-mining activities (>95% of total emissions), and the remainder are caused by leaks from oil and gas systems (5%). Since the "11th Five-Year Plan", numerous policies have been implemented in China with the aim of encouraging exploration and exploitation of coal-bed methane (CBM), increasing the utilization rates for CBM and coal-mine methane (CMM) and decreasing CH_4 emissions and leaks. In this study, we used national GHG emission inventories for China to investigate CH_4 emissions and possible ways of decreasing CH_4 emissions related to energy production activities by 2050, taking into account policies and techniques for decreasing CH_4 emissions. The aim of the study was to provide technical support and policy recommendations for developing mid- and long-term low-carbon development strategies for China.

2. Research Methods

2.1. Accounting for CH_4 Emissions in China

CH_4 emissions related to energy production activities in China occur mainly through CH_4 venting and fugitive emissions during production-related processes in the coal industry and the oil and gas industry. According to the IPCC inventory guideline, there are also biomass combustion methane emissions, which are not included in this paper because of data limitations.

2.1.1. Coal Industry

Coal industry CH_4 emissions occur in four main ways.

(1) CH_4 emissions during underground mining. CBM is continuously released into coal mine tunnels and caverns during underground coal mining and then emitted to the atmosphere through the ventilation and air extraction systems.
(2) CH_4 emissions during open-pit mining. CH_4 is released from coal mined in open pits and from adjacent exposed coal seams.
(3) CH_4 emissions during post-mining activities. Before coal is combusted, CH_4 is generated during activities such as coal cleaning, storage, transportation, and crushing.
(4) CH_4 emissions from abandoned mines. CMM will be slowly released into a mine and to the atmosphere for a certain period after the mine has been abandoned.

According to national emission inventories for China [45], CH_4 emissions during underground mining and post-mining activities contribute 97% of coal-related CH_4 emissions. Methane emissions from abandoned mines in 2020 account for 11.76% of coal methane emissions in the US greenhouse gas emissions inventory [45]. It has also been on an upward trend from 1990 until now. Methane emissions from abandoned mines in China coal methane emissions still accounted for about 1%, but the share of emissions is expected to grow with the increase in abandoned mines, following the US experience. Limited data are available; we estimated CH_4 emissions during underground mining and post-mining activities (the first two types of CH_4 emissions related to coal production activities). Therefore, results for coal mines methane emissions will be underestimated. In the 2012 inventory, CH_4 emissions during coal industry activities were estimated using mean CH_4 emission factors at tier 2. This is called the national or coalfield average method and is based on the amount of coal mined. The equations and methods used are shown in Table 1. The emission factors were taken from the 2012 national emission inventory for China [46].

Table 1. Methods used to estimate CH_4 emissions for energy industrial activities.

	Activity	Equation	Activity Level	Emission Factor
Coal industry	Underground mining	Amount of coal mined × emission factor per unit of coal mined	Amount of coal mined	10.59 m^3/t
	Post-mining activities	Raw coal output of underground coal mines × emission factor	Post-mining activities should be arranged based on the raw coal outputs of outburst mines, high gas mines, and gas mines nationwide.	• 3 m^3/t for high gas mines and outburst mines • 0.94 m^3/t for gas mines according to the current situation of the coal production industry in China
Oil and gas industry	Oil and gas exploitation-related steps: extraction, processing, and transmission	Facility/equipment × emission factor for the facility/equipment unit	For example, the numbers of well-head assemblies, compressor stations, transmission pipelines, and refineries	Mean emission factor based on output or a factor for a specific emission source

2.1.2. Oil and Gas Industry

Exploitation of oil and gas reserves causes GHGs (particularly CH_4) to be emitted during prospecting, drilling, well completion, oil/gas production, workover, gathering and transportation, purification, metering, storage, transportation, and oil refining and at the end-use site.

Gas venting and fugitive emissions release CH_4 and other GHGs during oil and gas exploitation. Venting means the necessary release of gases (including CH_4) during oil and gas exploitation. Venting occurs during storage tank breathing, pigging, oil and gas testing, workover, and other technical processes. Emissions through venting are also called process emissions. Different production processes and equipment can give very different venting emissions. Fugitive emissions of GHGs occur because of interfaces between equipment being poorly sealed or because of damage to equipment (e.g., aging of valves and piston seals, packing wear, pipeline corrosion, and sand hole perforation). The age, service life, maintenance, and operating conditions of equipment strongly affect fugitive emissions.

CH_4 emissions by the oil and gas industry were mainly accounted for using the compilation method, combining method 1 (the mean emission factor method based on outputs) and method 3 (the factor method based on specific emission sources) defined in the IPCC Inventory Guidelines. The IPCC default emission factors or oil and gas industry emission factors for other countries were used (see Table 1). Oil and gas reserves are exploited over long periods using complex production processes. There are many points at which venting and leaks occur because many types of equipment are constructed and used, including pipelines and interfaces, that have different venting emission patterns. Calculations using emission factors for specific emission sources can give fine-scale emission data, but the applicability of emission factors and availabilities of activity-level data mean the calculations may have relatively large errors.

2.2. Study Methods

The study of CH_4 emissions during energy production activities in China by 2050 was combined into two parts. The first part is related to a multiscenario study of future development. The second part is the estimation of CH_4 emissions during energy production activities. Future economic development and energy activities under different scenarios were compared in the multiscenario study. CH_4 emissions during energy production activities were estimated using the method for estimating CH_4 emissions in China mentioned above. These data and predicted energy activities under various scenarios were combined to estimate future CH_4 emissions. The whole research framework is shown in Figure 1.

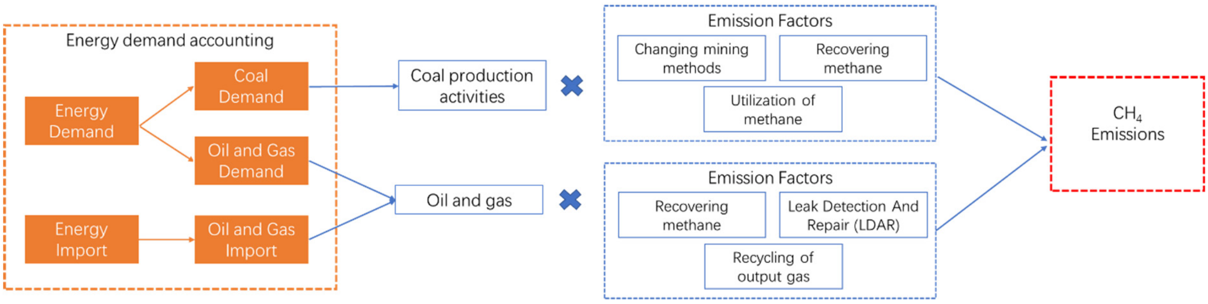

Figure 1. Whole research framework.

Three scenarios were compared and analyzed. These were a business-as-usual (BAU) scenario, an NDC scenario, and an extreme scenario. For the coal mining and production, in all three scenarios, coal production will peak by 2020 and then decrease until 2050, but the production peaking values show small differences, and the decrease rates show different trends. The latter scenario is decreasing faster than the former scenario. The detailed descriptions are shown in Table 2.

Table 2. Scenario description.

Scenario	Assumptions	
	Activity	Emission Factor
BAU	Keep the current development, coal production keeps increasing by 3.9 billion tons in 2020 and then decreases by 2.9 billion tons by 2050. The annual decrease rate for the period from 2020–2030 will be −1%, and double from 2030–2050.	keep current methane recovery and utilization level of annual 20 billion cubic meters
	Oil and gas consumption will peak by 2035, holding at 1.6 billion tce, oil consumption will peak earlier than gas consumption.	Freeze, keep the current national inventory factors
NDC scenario	Coal production keeps increasing by 3.9 billion tons in 2020 and then decreases by 1.5 billion tons by 2050. The annual decrease rate for the period from 2020–2030 will be −3% and remain 4% from 2030–2050.	encourage the recovery and utilization of low concentration methane after 2020, increase the utilized rate by more than 60%
	Oil and gas consumption will peak about 2030, holding at 1.5 billion tce.	lag five years compared with the same period in US
Extreme scenario	Coal production keeps increasing by 3.9 billion tons in 2020 and then decreases by 0.7 billion tons by 2050. The annual decrease rate for the period from 2020–2030 will be −8%, and −5% from 2030–2050.	encourage the recovery and utilization of low concentration methane after 2020, increase the utilized rate by more than 65%
	Oil and gas consumption will peak about 2025, holding at 1.4 billion tce.	lag three years compared with the same period in US

The BAU scenario was based on current development trends in the energy sector, with emission factors that were assumed to remain constant. The NDC scenario took NDC actions taken by China [47] and decreased CH_4 emissions into consideration as coal consumption decreased, in particular recovery and use of coal-mine gas and oil and local gas production. The carbon peaking target in the NDC scenarios requires control of the growth of coal consumption in the 14th five-year plan period and gradual reduction of it in the 15th five-year plan period. It was assumed that large amounts of oil and natural gas will be imported into China in the future and that China will become increasingly dependent on imports compared with BAU. It was assumed that oil and gas use in China will peak about 2030 at 1.5 billion tce and then slowly decrease. It was assumed that coal production and consumption will be increasingly controlled and decreased but that natural gas will be used as an alternative energy source and therefore be consumed in increasing amounts. The decline in coal production and the recovery and utilization of coal- mine methane is expected to reduce coal methane emissions directly but increase oil and gas methane due to oil and gas production and imports. In the NDC scenario, natural gas use increased initially, then remained slightly increased, but the contribution of natural gas to total energy consumption increased. Various technical measures and low-carbon economic transformation were taken into account in the extreme scenario. These changes and the latest Chinese carbon-neutral target were expected to force the energy system to develop and transform increasingly quickly. In this scenario, it was assumed that coal will cease to be used by 2050 and that oil and gas use will peak between 2025 and 2030 at 1.4 billion tce per year and then slowly decrease. Oil demand was expected to decrease sharply after reaching a peak in 2030, but natural gas use was expected to increase rapidly in the initial period and then steadily decrease (shown in Tables 2 and 3).

The main emission factors adopted are shown in Table 3. For the emission-factor consideration for coal mining, BAU will adopt the frozen scenario, which means there is no more CH_4 recovery and utilization. The NDC and extreme scenarios will expand and encourage the recovery and utilization of low concentration methane. For the oil and gas industry, predictions were made for the three energy scenario models for the relevant types of energy but not taking the amounts of equipment used and the activities of the energy industry into consideration. A lack of basic activity and equipment data for China meant it was not possible to estimate future CH_4 emissions by the oil and gas industry using the Chinese national emission inventory method. Because the US EPA has published the detailed emission factors for the main production process, this paper first calibrated the base year emissions based on China national GHG inventory and the main production process in US. That means based on China's emissions, according to the production process of the US, the emissions factor is converted on the base year. Moreover, the emission factors for the future will utilize the change trend in the US. In particular, as for the emission factor of natural gas, based on the analysis comparing the change trend of the EAP emission factor, it can be found that the natural gas production, distribution, and logistics factor change is not large, mainly because most of these facilities select emission reduction technology and related management systems, and the exploration and processing factors present a downward trend. It is mainly related to the continuous optimization of mining technology facilities. Therefore, the BAU scenario in this paper is set as the technology freeze scenario; that is, the factors of future years and base years remain unchanged, whereas the NDC scenario assumes that the change rate of exploration and treatment factors in China lags behind that of the US for five years, while other factors remain basically unchanged. The extreme scenario assumes that the rate of change lags three years behind that of the US.

Table 3. Main parameters.

Year	2020	2025	2030	2035	2040	2045	2050
Activity							
Coal production (Billion tons)							
BAU	3.90	3.90	3.90	3.73	3.30	3.10	2.90
NDC	3.90	3.53	3.00	2.71	2.05	1.76	1.46
Extreme Scenario	3.90	2.80	1.86	1.27	0.94	0.80	0.66
Oil production (Million tons)							
BAU/NDC/Extreme Scenario	195	195	200	199	197	189	180
Gas Production (Billion cubic meters)							
BAU/NDC/Extreme Scenario	192	203	247	300	328	345	350
Main Emission Factor							
Coal mining emission factors (m^3/ton)							
BAU	10.59	10.59	10.59	10.59	10.59	10.59	10.59
NDC	10.59	10.36	10.13	9.67	9.21	8.98	8.75
Extreme Scenario	10.59	10.2	9.78	9.2	8.505	8.16	7.81
Oil exploration emission factors (t CH_4/million tons)							
BAU	586	746	781	942	795	648	600
NDC	586	746	781	942	795	648	600
Extreme Scenario	586	580	483	386	149	25	25
Oil production emission factor (t CH_4/million tons)							
BAU	4063	4106	4097	3900	3821	3708	3593
NDC	4063	4097	4137	3821	3708	3593	3095
Extreme Scenario	4063	3821	3295	2768	2579	2550	2550
Oil transportation (t CH_4/million tons)							
BAU/NDC	16.6	16.5	16.8	16.7	15.3	15.0	15.2
Extreme Scenario	16.6	15.3	15.2	15.7	14.8	13.4	13.4
Gas production emission factors (t CH_4/Billion cubic meters)							
BAU	7311	7520	7420	7513	7342	7177	6860
NDC	7311	7420	7513	7342	7177	6860	6647
Extreme Scenario	7311	7342	6860	6156	5880	5904	5904
Gas transportation and storage (t CH_4/Billion cubic meters)							
BAU	1900	1900	1900	1900	1900	1900	1900
NDC	1900	1900	1801	1801	1801	1801	1801
Extreme Scenario	1900	1900	1838	1848	1763	1763	1763

3. Research Results

3.1. Overall CH_4 Emissions

In the BAU scenario, energy-related CH_4 emissions could peak in 2030. CH_4 emissions will then then decrease slightly by 2030 and then decrease markedly after 2035. It was estimated that emissions will be 25% lower in 2050 than 2020, equivalent to a mean annual decrease of around 1% (Figure 2). The main contributor to the decrease in CH_4 emissions was found to be the coal industry, emissions from which were predicted to be 35% lower in 2050 than 2020 (a mean annual decrease of 1.4%). This was mainly attributed to implementing national coal control policies. CH_4 emissions by the oil and gas industry were predicted to increase each year and be 48% higher in 2050 than 2020 (equivalent to a mean annual increase of 1.3%).

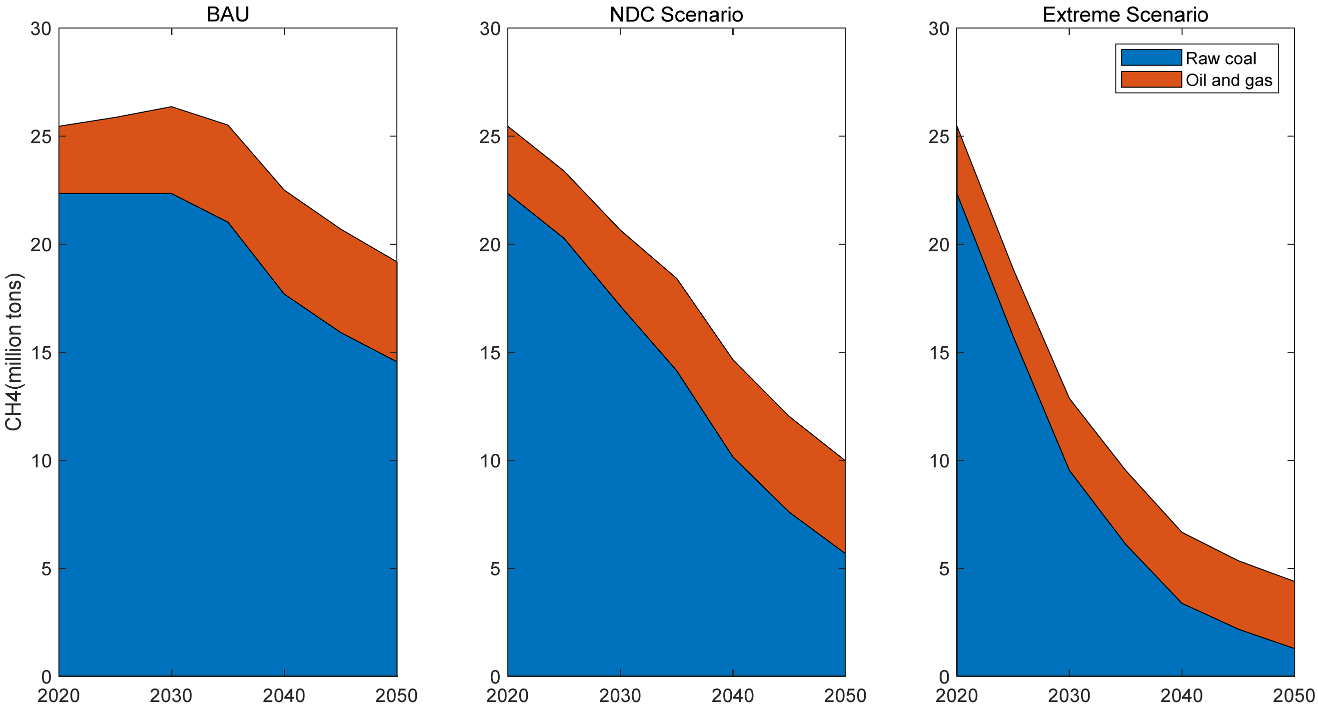

Figure 2. Energy-related CH_4 emissions by 2050.

Some of the decrease in coal production and consumption was predicted to be replaced with oil and gas consumption, meaning production and consumption of oil and gas in China would increase. The overall structure of CH_4 emissions by the energy industry were predicted to change. The results indicated that the contribution of the coal industry to total CH_4 emissions would decrease from 90% in 2020 to 76% in 2050, but the contribution of the oil and gas industry would increase from 10% in 2020 to 23% in 2050. Using oil and gas as transitional clean energies to replace coal would increase CH_4 emissions by the oil and gas industry, but total CH_4 emissions by the energy industry would continue to decrease because of considerable decreases in CH_4 emissions by the coal industry.

Although estimation in this paper represents a bottom-up method for CH_4 emission in China, there are still various uncertainties and barriers to this trend. For example, as mentioned in the method introduction, potential technology progress, especially in the oil and gas industry, is not considered completely, because methane control is still at the starting stage in China and there are not many more cases and unique criteria. In addition, reduction cost overtime is not considered.

This paper compared with current studies future methane emissions for China from the energy industry (Figure 3). Based on the different assumptions from various studies, there are still big gaps; for example, by 2030, most studies still predicted increased CH_4 emissions from energy industries because there are no more methane control policies and measures assumptions. This paper estimated that the methane emissions from energy industries can peak about 2025.

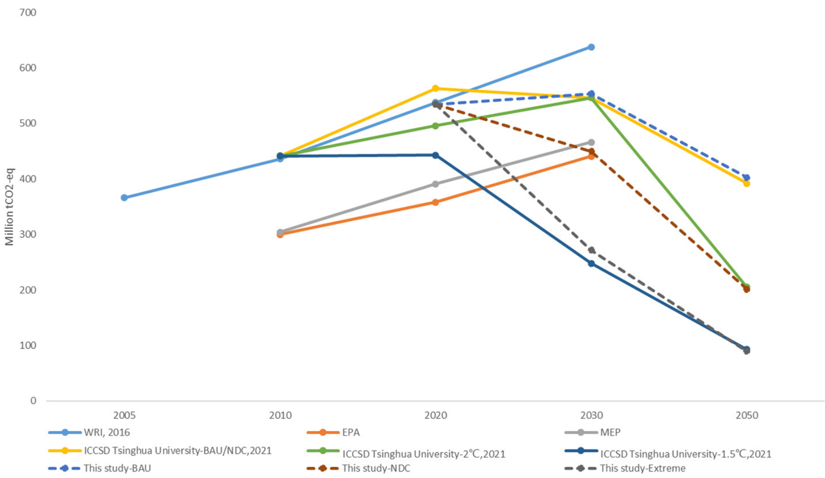

Figure 3. Comparison with other studies.

3.2. CH_4 Emissions by the Coal Industry

Policies aimed at controlling coal production and consumption will lead directly to a rapid decrease in CH_4 emissions by the coal industry. In the NDC scenario, keeping coal output at about 1.5 billion tons in 2050 will require a mean annual decrease in coal production capacity of >10%. Keeping CMM emissions at 6 billion m^3 will cause CH_4 emissions by the coal industry to be >60% lower in 2050 than 2020.

For the extreme scenario, it was expected that coal use would completely stop by 2050. Keeping CMM emissions at 4 billion m^3 would estimate CH_4 emissions by the coal industry at 1.3 million tons in 2050, which is effectively close to zero emissions (Figure 4) and a good foundation for achieving the target of being carbon neutral by 2060. After the rapid phasing-out of coal, if the annual decrease rate will remain 20%, CH_4 emissions from coal production will dramatically decrease, while CH_4 emissions from the post-mining activities will account for a large share. This indicates that decreasing CH_4 emissions by the coal industry will both require coal production to decrease and emissions caused by post-mining activities to be managed.

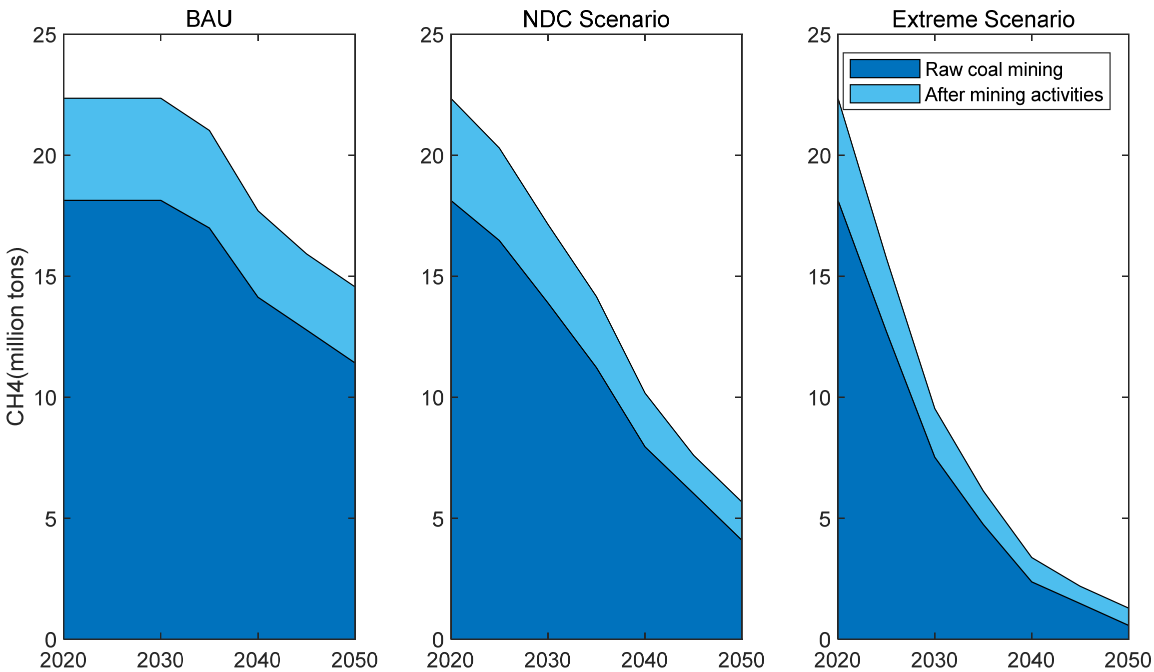

Figure 4. CH_4 emissions by the coal industry by 2050.

3.3. CH_4 Emissions by the Oil and Gas Industry

CH_4 emissions by the oil and gas industry currently make relatively small contributions to CH_4 emissions by the energy industry in China. However, the total amount of CH_4 emitted and the contribution of the oil and gas industry to total CH_4 emissions will increase as coal production and consumption decrease because oil and gas production capacity will increase to compensate. Annual oil output in China was estimated to remain at 200 million tons. In the BAU scenario, total oil demand was predicted to peak in 2030 at 800 million tons. CH_4 emissions caused by oil production were therefore expected to peak before 2030, start to slowly fall from 2035, and to return to the 2020 emission value in 2050.

For the BAU scenario, it was estimated that CH_4 emissions by the oil and gas industry in China will be 48.5% higher in 2050 than 2020, equivalent to a mean annual increase of 1.3% (Figure 5). The natural gas production capacity is expected to increase, causing CH_4 emissions by the oil and gas industry to peak in 2040 and remain stable until 2050. CH_4 emissions caused by natural gas production and use were predicted to contribute >80% of CH_4 emissions by the oil and gas industry, so CH_4 emissions by the oil and gas industry will need to be controlled mainly by decreasing natural gas venting and fugitive emissions.

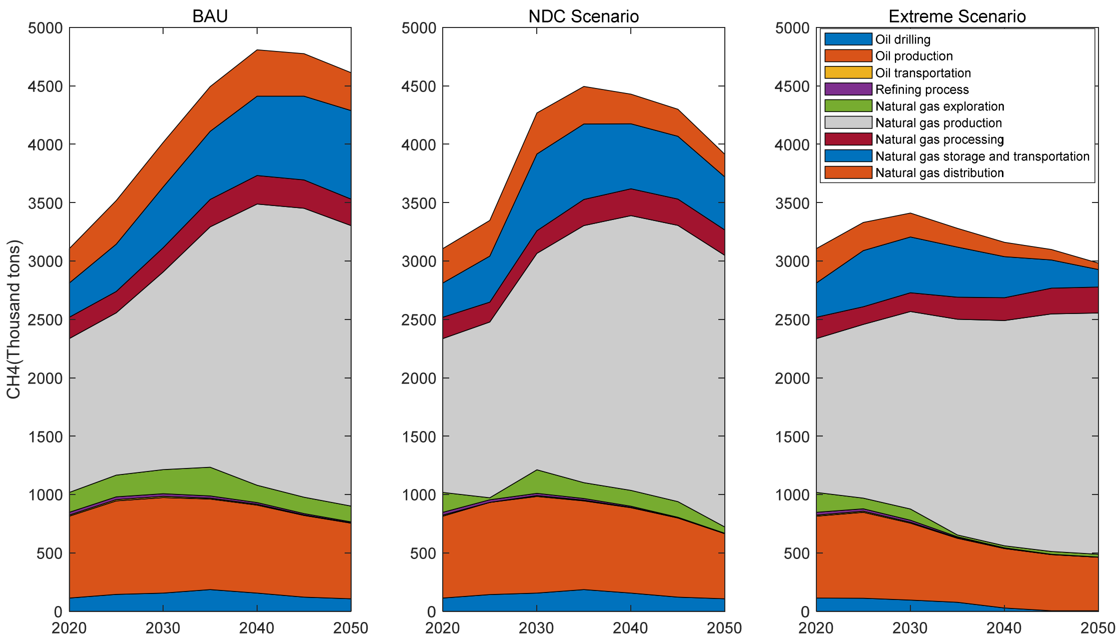

Figure 5. CH_4 emissions by the oil and gas industry by 2050.

3.4. Comparison of the Different Scenarios

Predicted CH_4 emissions by the energy industry for the different scenarios are shown in Figure 6. CH_4 emissions by the coal industry could be effectively controlled by 2050 by decreasing coal consumption and increasing the amount of CH_4 recycled. For example, CH_4 emissions would be decreased by 90% in the extreme scenario. CH_4 emissions were found to be decreased more for the coal industry than the oil and gas industry for all three scenarios. CH_4 emissions by the oil and gas industry for the different scenarios were not very different, but the contributions of the oil and gas industry to total emissions were markedly different for the different scenarios. The contribution of the oil and gas industry to CH_4 emissions is currently not very high. However, implementing coal control policies will cause CH_4 emissions by the coal industry to decrease. CH_4 emissions by the oil and gas industry (which will change little in terms of the actual amount of CH_4 emitted) will contribute more to total emissions. The contributions of the coal industry were higher than the contributions of the oil and gas industry in most of the scenarios. Actual CH_4 emissions will be decreased more by controlling coal industry emissions than by controlling oil and gas industry emissions. Controlling the coal industry is therefore key to decreasing CH_4

emissions by the energy industry. In the extreme scenario, CH_4 emissions by the oil and gas industry were predicted to contribute up to around 70% of energy-related CH_4 emissions in 2050. CH_4 emissions by the oil and gas industry will therefore need to be decreased to achieve the target of carbon-neutral energy production.

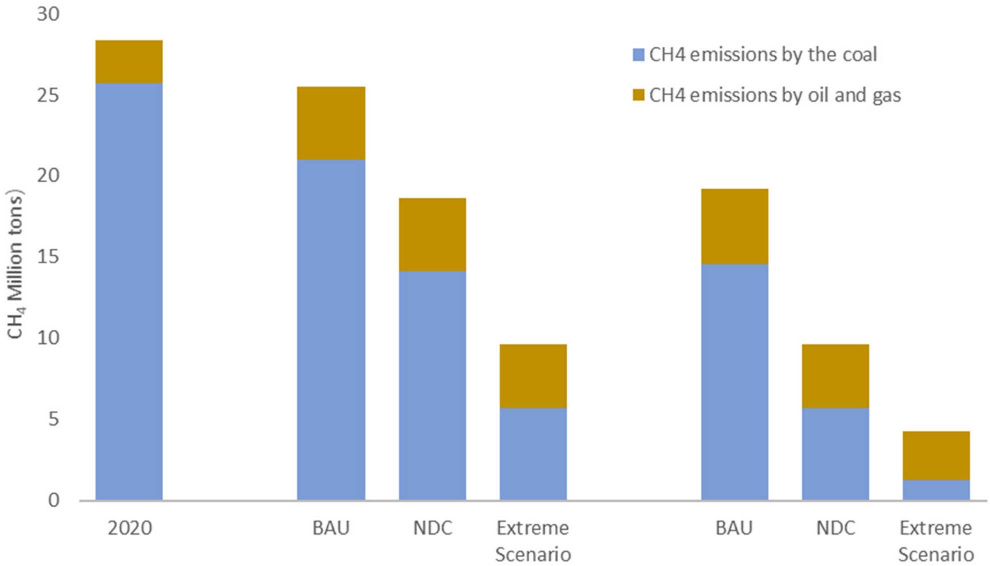

Figure 6. CH_4 emissions by the energy industry for the different scenarios.

4. Conclusions

4.1. Methane Emissions from China's Energy Sector Are Likely to Have Stabilised and Can Be Peaking with CO_2 Emissions

The results in this paper show that even with the current policy scenario, energy-related methane emissions are expected to peak by 2030, with emission levels remaining at approximately 26 Mt. Due to the relatively high share of coal methane emissions, energy methane emissions are expected to decline by around 3–10% overall in 2035 compared to 2030 as coal consumption and production are effectively controlled. Although methane emissions from the oil and gas sector currently account for a relatively small proportion of energy sector methane emissions, their methane emission trends will increase as gas production and consumption increases but will largely not cause a significant increase in energy methane emissions. Methane emissions from the energy sector can be effectively curbed in the near term by controlling coal production, but in the long term its emissions will need to be controlled through technical means, such as recycling and enhanced detection.

4.2. Methane Emissions from Energy Sector will Be Reduced in the near Term by Controlling the Level of Production Activity, but in the Long Term it Will Still Require the Deployment of Abatement Technologies to Achieve Deeper Reductions

In addition to controlling energy production, the expansion of energy methane recycling technologies can effectively reduce emission factors and is expected to play an important role in accelerating the reduction of energy methane emissions beyond 2030, especially as increased natural gas consumption will inevitably lead to increased methane emissions once coal production is effectively controlled, and improved monitoring and recycling will offset some of this growth and will inevitably help to achieve a carbon-neutral reliance on negative emission technologies in the longer term.

4.3. Emissions Accounting System for Energy Methane Emissions Still Needs to Be Improved

It is very difficult to estimate CH_4 emissions by the energy industry because of difficulties involved in determining emission factors. Problems related to the data or the applicability of the emission factors were addressed by adjusting the emission factors for the coal industry and the oil and gas industry to minimize uncertainty. It has been suggested that during the "14th Five-Year Plan" period, China should improve the verification system for estimating CH_4 emissions by the energy industry at the national level, examine and improve the data acquired, develop more scientifically justified and reasonable emission factors, and formulate guidelines for the method used to compile CH_4 emission inventories for a wide range of companies. Companies should also be trained to manage CH_4 emissions using the experiences of companies in developed countries.

5. Discussion

In 2020, the European Commission issued the "EU Methane Strategy", which introduced 24 actions to decrease CH_4 emissions in the European Union and internationally and required CH_4 emissions by the energy, agriculture, and waste treatment sectors to be decreased. In the strategy, it was stated that energy production is the key sector for decreasing CH_4 emissions quickly and cheaply. The US has adopted a range of policies to decrease CH_4 emissions by the oil and gas industry, combining laws and regulations with voluntary activities to decrease emissions. The US federal government has developed national environmental air quality standards and national emission standards. Other countries such as Canada and Mexico have also implemented their NDC actions to control CH_4 emissions by the oil and gas industry. Numerous voluntary initiatives for decreasing CH_4 emissions have also been proposed by the global energy industry. These include the Global Methane Initiative, the Oil and Gas Methane Partnership (developed by the Climate and Clean Air Alliance and the United Nations Environment Programme), and the Oil and Gas Climate Initiative. All of these initiatives include a commitment to track and decrease CH_4 emissions by key sectors and to promote research and other efforts to decrease CH_4 emissions.

Efforts to decrease energy-related CH_4 emissions in China started later than efforts to decrease energy-related CO_2 emissions. Nonetheless, there is great potential for decreasing CH_4 emissions, and decreasing CH_4 emissions should be one of the priorities for decreasing GHG emissions in the future. In the "12th Five-Year Plan", the Chinese government proposed an overall plan for encouraging improvements in CMM use and surface CBM exploitation to decrease CH_4 emissions from coal mines. The Chinese government published Accounting Methods and Report Guidelines for Greenhouse Gas Emissions from Oil and Natural Gas Production Enterprises in China to provide guidance to help oil and gas companies compile GHG inventories. In the Work Plan for Controlling Greenhouse Gas Emissions, part of the "13th Five-Year Plan" period, the Chinese government proposed to improve recycling of vented natural gas and gas associated with oilfields.

One way of decreasing CH_4 emissions from underground coal mines is to reorganize and integrate the industry to decrease CH_4 emissions from small, scattered coal mines. Other ways are to extract as much CH_4 as possible before mining or collect CH_4 released during mining. In 2018, 18.4×10^9 m^3 of CBM were extracted in China and 10.2×10^9 m^3 of CBM were used. In the Action Plan for Coalbed Methane Exploration and Exploitation it was proposed that 20×10^9 m^3 of CBM would be extracted each year by 2020 and 60% would be used. The volume of CMM extracted and the amount of CBM exploited have recently increased each year. However, the large annual CMM output means there is still great potential for recycling CMM.

Clear targets and requirements for controlling energy-related CH_4 emissions have not yet been set in China. Current policies for controlling CH_4 emissions by the energy industry are dominated by mandatory policies aimed at ensuring safe energy production and suggestive policies to encourage and provide guidance for CBM exploitation and utilization. These policies do not effectively persuade companies to recycle CH_4. Oil and gas production in China is mainly performed by a few large state-owned companies. Some companies have spontaneously participated in initiatives or alliances to control CH_4 emissions. However, strong decreases in CH_4 emissions will be difficult to achieve in the absence of a target for controlling CH_4 emissions set by the Chinese government, even though loose voluntary actions and initiatives can improve awareness and the ability to control CH_4 emissions. The value of recycling CH_4 can offset some of the costs of decreasing emissions. The International Energy Agency has estimated that 50% of CH_4 emitted by the oil and gas industry can be avoided at no cost, indicating the huge potential for decreasing CH_4 emissions.

The low initial costs of decreasing CH_4 emissions and the economic benefits of recycling CH_4 have led the Chinese government to consider formulating targets for controlling CH_4 emissions in line with national targets for decreasing GHG emissions and in accordance with the stages of development of the techniques required to control and recycle CH_4. It has been suggested that clear targets for decreasing CH_4 emissions and guidance for control standards should be formulated during the "14th Five-Year Plan" period. Efforts to decrease coal production and consumption in China are being strengthened, and it has been suggested that targets for absolute amounts of CH_4 that may be emitted by the coal industry should be set. Recommendations for CH_4 recycling and utilization rates and CH_4 leakage rates (emission intensities) for the oil and gas industry should also be made. A complete and sound CH_4 emission inventory should be established to allow the recommended CH_4 emission limits to be set. Leak rate indices to allow international benchmarking should be set, particularly for new and modified oil and gas wells.

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