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A Study on Synergizing the Reduction of Air Pollution and Carbon Emissions in China and Policy Implication

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Most conventional air pollutants and carbon dioxide (CO_2) are simultaneously emitted from the same sources, providing a sound theoretical basis for the synergistic governance of these emissions. At present, China faces severe challenges in protecting the eco-environment, such as reducing conventional pollutants, improving environmental quality, and peaking CO_2 emissions. Internationally, the control of greenhouse gas (GHG) emissions has been incorporated into the comprehensive environmental management system in major developed economies such as the United States (US) and the European Union (EU), where, based on GHG emissions monitoring and statistical data, decision-making support is provided for the national governments in the form of policy evaluation, thus forming a management mode that enables overall planning, coordination, and unified regulatory at the national level and participation of multiple departments under the national government. The synergistic control of conventional air pollutants and GHGs is becoming an important measure to strengthen the environmental management and achieve low-carbon development. This paper summarizes the synergistic effects of reducing air pollution and carbon emissions from the aspects of synergistic policies, strategic planning, and institutional systems, and conducts an analysis based on existing synergistic practices.

Keywords: Synergistic governance; air pollution; carbon emissions.

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1. The Basic Meaning of Synergistic Governance

1.1. *The concept of synergy and situations in China*

1.1.1. *The concept of synergy*

As emissions of different gases are related, climate policies aimed at reducing greenhouse gas (GHG) emissions and policies aimed at controlling air pollution will affect each other to some extent. In other words, the implementation of one type of policies may produce a synergistic effect on the realization of another policy's objectives. Academia has undergone some shifts in the conceptual understanding of policy's synergistic effect. As early as 1992, David Pearce put forward the concept of "secondary benefits", arguing that policies to control GHG emissions are not necessarily effective in reducing the costs. Still, many CO_2 emissions reduction policies can create secondary benefits by reducing other pollutants such as SO_2 and NO_x, and such secondary benefits can be 10–20 times the primary benefits created by GHG emission reduction (Pearce, 1992). Afterwards, the Intergovernmental Panel on Climate Change (IPCC) cited the concept of secondary benefits in the *IPCC Second Assessment Report: Climate Change 1995* (IPCC, 1995), and for the first time defined the term "co-benefits" in the *IPCC Third Assessment Report: Climate Change 2001*, that is, the non-climate benefits of GHG mitigation policies that are explicitly incorporated into the initial creation of mitigation policies (IPCC, 2001). In the *IPCC Fourth Assessment Report: Climate Change 2007* and the *IPCC Fifth Assessment Report: Climate Change 2014*, IPCC also wrote about synergies between fossil energy use reduction, GHG emission reduction, and air quality improvement (IPCC, 2007, 2014).

According to China's official definition, co-benefits or synergistic effects refer to not only the reduced emissions of other local air pollutants, such as SO_2, NO_x, CO, VOC, and PM, in the process of controlling GHG emissions, but also the reduction or absorption of CO_2 and other GHGs in the process of controlling local air pollutant emissions and protecting the eco-environment. As China's energy mix is dominated by fossil energy, most CO_2 and major air pollutants are simultaneously emitted from the same sources. The coal-dominated energy mix has resulted in 90% of SO_2 emissions, 67% of NO_x emissions, 70% of soot emissions, and 70% of CO_2 emissions in China from coal combustion. CO_2 emission control measures and technologies (in addition to CO_2 capture, utilization and storage technologies) can also have a significant impact on the air pollutants that are generated along with CO_2.

1.1.2. *China faces strict challenges in air quality improvement*

Since 2013, through the implementation of the Three-year Action Plan for Winning the Blue Sky Defense Battle and the Air Pollution Prevention and Control Action Plan, China has launched a host of major initiatives in air quality management mechanism, structural adjustment, and major emission reduction projects, resulting in marked improvement in air quality. In 2020, 202 of the 337 (59.9%) prefecture-level cities in China met the air quality standards; the average $PM_{2.5}$ concentration for Chinese cities reduced to 33 $\mu g/m^3$, which was 34% lower compared to the 2015 level. Besides, the proportion of days with good air quality throughout the year reached 87.0%. Although China has achieved marked progress in air quality, there is still a big gap in reaching the level that effectively protects human health, and the gap is manifested in the following three aspects.

First, the overall air quality has improved, but some of the indicators have turned worse again or with limited improvement. Compared with 2015, there was a significant reduction in heavy air pollution in 2020, and the pollution concentration, duration, intensity, and impacted areas were markedly reduced, despite that the O_3 concentration was slightly increased. Second, pollution has become a more prominent problem in some regions, and air pollution in key regions remains severe. With the increasingly stronger correlation of industrial development and transportation systems among regions, and the influence of regional climate and meteorological conditions, many places in China have shown prominent features of regional air pollution, and transferred pollutants from one to another, making it necessary to further increase the scope and strength of joint prevention and control. In 2020, the concentrations of $PM_{2.5}$ in the Beijing–Tianjin–Hebei region and its surrounding areas (BTH) and Fenwei Plain region exceeded the standard by 45.7% and 37.1%, respectively. Third, the characteristics of air pollution have changed, and the atmospheric oxidation capacity (AOC) has been increasing. In 2020, 337 prefecture-level cities in China reached the standard for SO_2 concentrations, indicating that the soot pollution was under effective control. However, O_3 concentrations continued to rise nationwide, and increased by about 11% in the BTH region areas.

1.1.3. *The challenges in peaking CO_2 emissions*

Along with the sustained economic growth, China's CO_2 emissions have continued to increase in recent years. The nationwide CO_2 emissions increased from 5.7 billion tons in 2005 to 10.6 billion tons in 2018. Since the 12th Five-Year Plan period, the growth rate of CO_2 emissions had decreased, with an annual average growth rate of 2.53%. From the late 12th Five-Year Plan period to the middle 13th Five-Year Plan period, although the growth rate of CO_2 emissions had slowed down, the total amount of emissions kept growing, with an annual average growth rate of 2.49% within the 13th Five-Year Plan period. By 2018, China's CO_2 emissions already accounted for about 30% of the world's total without an obvious sign of reaching the peak. From the perspective of key regions, CO_2 emissions in the BTH region have remained at about 1 billion tons since 2011. During the 13th Five-Year Plan period, the average annual growth rate of CO_2 emissions in the BTH and Yangtze River Delta (YRD) region was 0.29% and 2.4%, respectively.

2. Progress in Synergetic Governance

2.1. *International experience in synergetic governance*

In terms of international experience, major developed countries focus on addressing climate change and preventing environmental health risks, combine environmental quality targets with climate change mitigation and adaptation, actively promote the synergetic control of climate, environment, and health, and implement unified environmental regulation.

Major economies such as the European Union (EU) and the United States (US) have incorporated the control of GHG emissions into the comprehensive environmental management system, thus forming a management mode that enables overall planning and coordination as well as unified regulations at the national level and participation of multiple departments. The European Commission is responsible for setting GHG and air pollution control targets and assigning the control targets to each EU member state. The EU Directorate-General for Climate Action is the policy implementing agency that maintains leadership in climate action and ozone layer protection.

The Office of Atmospheric Programs (OAP) under the Office of Air and Radiation (OAR) of the US. Environmental Protection Agency (EPA) is concerned with clean air markets and climate change according to the Clean Air Act, with its responsibilities including the GHG monitoring and the preparation and publication of GHG emission inventories. In December 2007, the OAP began to implement the mandatory Greenhouse Gas Reporting Program (GHGRP). According to the National Ambient Air Quality Standards (NAAQS) established by EPA, each state formulated and implemented its State Implementation Plan (SIP) to fulfill the requirements of the Standards. In addition, the US adopts an environmental management system known as the Prevention of Significant Deterioration (PSD) permitting program to effectively prevent air pollution and control GHG emissions.

In terms of GHG monitoring, the US and the EU have built relatively complete monitoring systems for GHG emissions based on the principle that mainly focuses on accounting with monitoring as a supplement. In 2009, the EPA issued a plan for mandatory reporting of GHG data from large GHG emission sources within the US. In 2004, the EU formulated the Guidelines for the Monitoring and Reporting of Greenhouse Gas Emissions (2004/156/EC), which detailed the criteria of monitoring and reporting GHG emissions for enterprises from 23 industrial sectors. The Guidelines had been revised several times, and its latest version, the Regulation on the Monitoring and Reporting of Greenhouse Gas Emissions (EU2018/2066), was issued on December 19, 2018. Moreover, in terms of GHG regulation, the EU takes both market-based and command-and-control measures to regulate different GHG emission sources. For one thing, the EU uses the carbon emissions trading system to control the total emissions from large stationary emission sources through market-based measures; for another, the EU uses command-and-control measures similar to air pollution control to regulate other emission sources.

2.2. *Progress in academic research domestically and internationally*

The research on synergistic benefits is mainly based on scientific and engineering methods and economic models, and its steps include: calculating GHG emissions and pollutant emissions or concentrations under the baseline and different policy scenarios, estimating and comparing the impacts of GHG or pollutant emissions, and then quantifying or monetizing the impacts. The key is to quantitatively estimate the emission reductions or concentrations of GHGs and pollutants through a coupled energy-emissions-impact assessment model.

At present, there are two main research directions for the synergistic reduction of GHGs and air pollutants: (i) GHG emissions reduction leads to the reduction or increase of air pollutants; (ii) regional air pollutants reduction leads to the reduction or increase of GHGs. Existing studies have been carried out at global, national, regional, and urban scales. A literature review shows that: (i) The synergistic benefits of GHGs and air pollutants were usually assessed by a comprehensive model that integrates energy system model, air quality model, and health impact assessment model, and these studies discussed the synergistic benefits of low-carbon and climate policies that are incorporated into carbon trading policies, Intended Nationally Determined Contributions (INDC) targets, electrification, energy efficiency improvements, and sectoral mitigation measures. Some studies focused on the synergistic benefits of peaking carbon emissions and were mainly conducted at the global or national level. Besides, most studies did not incorporate various synergistic benefits and emission reduction costs into their assessment models (Radu *et al.*, 2016; Rafaj *et al.*, 2010; He *et al.*, 2010; Chae, 2010). (ii) Most of the studies pointed out that GHG or pollutant emission reduction policies and measures can bring positive co-benefits, which are manifested as coordinated emission reductions, coordinated health benefits, and coordinated economic benefits (Peng *et al.*, 2017; Liu *et al.*, 2013; Ou *et al.*, 2018). However, it should also be cautioned that GHG emission reduction may increase pollutant emissions; conversely, pollutant emission reduction measures may also increase GHG emissions (Qin *et al.*, 2017). (iii) Although scholars believe that the reduction in pollutants or GHG emissions can bring positive synergistic benefits, their benefits differ among regions. Thus, assessing synergistic benefits and coordinating management should be given according to various situations, and management measures should be tailored to local conditions.

3. Synergistic Governance Measures to Reduce Pollution and Carbon Emissions

3.1. *Policy documents related to synergistic governance*

China's current policy documents related to the synergistic governance of pollutants and GHGs are shown in Table 1, including the guiding opinions, technical guidelines, control standards, and laws and regulations. These policy documents focus on the following: Synergistic benefits and coordinated control of GHG and pollutant emissions, accounting methods of coordinated control, CO_2 capture, utilization and storage technologies, control and monitoring of pollutant and GHG emissions, optimization of industrial layout and adjustment of energy mix, and promotion of clean energy production and utilization.

3.2. *Coordination and integration of strategies and plans*

To strengthen the coordination of strategies at the macro level, it is not only necessary to take tackling climate change as an important part of achieving the Beautiful China target and a key to integrate environmental protection into macroeconomic governance, but also to fully consider the connections between tackling climate change and the major sectoral and local strategies and plans that include energy production and consumption revolution, and to formulate relevant future plans. To promote the synergistic emission reduction of GHGs and pollutants, it is necessary to formulate coordinated control plans in industry and

Table 1. Policy documents, laws, and regulations related to synergistic governance.

Name	Issuing authority and year	Related content
Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution	Revised by the Standing Committee of the National People's Congress in 2018	It is necessary to implement joint prevention and control of regional air pollution, and carry out coordinated control of GHGs and air pollutants such as particles, SO_2, NO_x, VOCs, and ammonia. Measures should be taken to adjust the energy structure and promote the production and the use of clean energy; optimize the use of coal, promote clean and efficient use of coal, gradually reduce the proportion of coal in primary energy consumption, and reduce the air pollutant emissions in the process of coal production, use and conversion. Citizens should enhance their awareness of air quality protection, turn towards a low-carbon and thrifty lifestyle, and consciously fulfill the obligations of protecting the atmospheric environment. The Nation should promote low-carbon and eco-friendly travel, reasonably control the number of fossil-fuel vehicles according to urban planning, vigorously develop public transport, and increase the use of public transportation.
Environmental Protection Law of the People's Republic of China	Revised by the Standing Committee of the National People's Congress in 2014	It is necessary to promote clean production and resource recycling. Enterprises should give priority to the use of clean energy, adopt facilities, and processes with higher resource utilization efficiency as well as low pollution discharges, and apply comprehensive waste utilization and disposal technologies to reduce pollutant production.
Law of the People's Republic of China on Promoting Clean Production	Revised by the Standing Committee of the National People's Congress in 2012	Cleaner production used in this law means the continuous application of measures for design improvement, utilization of clean energy and raw materials, the implementation of advanced processes, technologies, and equipment, improvement of management and comprehensive utilization of resources to reduce pollution at source, enhance the rates of resource utilization efficiency, reduce or avoid pollution production and discharge in the industrial process, provision of services and product use, so as to decrease the impact to the health of human beings and the environment.
Guiding Opinions on the Coordination and Strengthening of the Work related to Climate Change and Ecological Environment Protection	Formulated by the Ministry of Ecology and Environment in 2021	It is important to highlight the synergistic benefits. Carbon reductions should be prioritized in addressing pollution at the source. At the same time, coordinated efforts should be made to control GHG and pollutant emissions and to promote climate change adaptation and the protection and restoration of ecosystems, so as to strengthen the efforts to prevent and control pollution and peak CO_2 emissions.
Technical Guideline for Accounting the Removal of Pollutants and Co-control of Greenhouse Gases from Pollution Control Facilities of Industrial Enterprises (on Trial)	Formulated by the former Ministry of Environmental Protection in 2017	The Guideline stipulates the main content, procedures, methods, and requirements for accounting the removal of pollutants and co-control of GHGs from pollution control facilities of industrial enterprises. This Guideline shall apply to the accounting of reductions of GHGs and the removal of pollutants generated from the process in which industrial enterprises use desulfurization, denitration, and VOC treatment facilities to control waste gases.

Table 1. (*Continued*)

Name	Issuing authority and year	Related content
Technical Guideline for Environmental Risk Assessment of Carbon Dioxide Capture, Utilization and Storage (on Trial)	Formulated by the former Ministry of Environmental Protection in 2016	Based on the current conditions of technological development and application, the Guideline stipulates the general principles, content and framework procedures, methods and requirements, and can serve as a technical reference for the environmental risk assessment of CO_2 capture, utilization, and storage.
Standard for Pollution Control on the Landfill Site for Household Waste	Formulated by the former Ministry of Environmental Protection in 2008	This standard stipulates the pollutant emission thresholds and environmental monitoring requirements for household waste landfill sites, including methane and air quality.

agriculture, and strengthen the coordination of emission reduction from centralized disposal facilities of sewage and garbage. Furthermore, it is important to actively explore ways to formulate relevant standards for the coordinated control of GHGs and air pollutants, and promote the pilot cities to peak CO_2 and reach air quality standards.

In addition, it is necessary to strengthen the connection between the plans in different fields and sectors. It is important to make sound plans, fully incorporate tackling climate change into environmental protection plans, and coordinate plans for relevant policy measures and major projects to promote the transition of the economy, energy, and industries to green and low-carbon development. It is also important to integrate the concepts of green development and climate friendliness into the special plans for pollution prevention, ecological protection, and nuclear safety, and integrate the requirements for addressing climate change into China's national economic and social development plans as well as plans for key sectors such as energy and industry. Besides, coordinated efforts shall be made to promote the implementation of the goals and tasks such as structural adjustment and layout optimization, GHG emissions control, and enhancement of the adaptative ability to climate change.

3.3. *Coordination and integration of policies and regulations*

When considering the coordination and integration of laws, regulations, and policies, it is necessary to promote not only the formulation and revision of relevant laws and regulations, but also the coordination and integration of relevant standard systems as well as environmental and economic policies. Also, it is important to focus on the formulation of special laws to address climate change, and promote the formulation and revision of legislation and local regulations in related fields, such as ecological environmental protection, resource and energy utilization, territorial space development, and urban–rural planning and development. Moreover, the introduction and implementation of regulations on carbon emission trading need to be further promoted.

Besides, it is necessary to strengthen the formulation and revision of relevant standards, and establish a standard system framework, including management and technical standards such as carbon reduction assessment and performance evaluation standards, carbon emission accounting report and verification, and low-carbon evaluation standards, as well as the basic standards related to the eco-environment. It is also important to carry out research on the standards for the coordinated control of air pollutants and GHG emissions from mobile-source to further tap the potential of synergistic reduction.

In addition, it is necessary to develop a framework system of environmental and economic policies that actively tackle climate change. Local pilot projects should be promoted when promoting the coordination of policies for climate investment and financing. Furthermore, regarding the information disclosure, it is necessary to facilitate the legal disclosure of enterprises' environmental information related to the national carbon emission trading, and record enterprises' violations of laws and regulations in the environmental credit system.

3.4. *Coordination and integration of institutions and systems*

The coordination of institutions and systems comprises of three aspects: Statistical investigation, evaluation and management, and monitoring system.

First, more efforts should be made to conduct a statistical investigation of GHG emissions, gradually improve the system of statistical reports and special statistical surveys, and include management indicators related to climate change. Moreover, it is necessary to further improve the mechanism for compiling GHG inventories and carbon emissions accounting and assessment.

In terms of evaluation and management, the requirements of addressing climate change should be incorporated into the system of zone-based and region-specific eco-environmental controls, which is composed of "Three Lines and One List" (the red line of ecological protection, the bottom line of environmental quality, the upper-limit line of resource utilization, and the list of eco-environment access). It is also necessary to include climate change impacts into the scope of environmental impact assessment.

In addition, GHG monitoring should be incorporated into the eco-environment monitoring system, including non-CO_2 GHG emissions. Meanwhile, at the national level, it is important to properly use satellite remote sensing and other means to monitor land use types, distribution and changes, as well as land cover types and distribution, so as to provide sufficient support for the compilation of the national GHG inventory.

4. Synergistic Governance Practices and Future Prospects

4.1. *Synergistic governance practices*

4.1.1. *Evaluation of the coordinated management of CO_2 emissions and air pollution in Chinese cities (CAEP, 2020)*

The coordinated management of air pollutants and GHGs is based on a good theoretical basis and practical experience. At the city level, evaluating the coordinated management of CO_2 emissions and air pollution is feasible and an important way to control carbon emissions and improve air quality. Evaluating the current situation of such coordinated management in Chinese cities is conducive in optimizing the environmental management system at the city level, reducing government management costs, and the burden on enterprises.

The scope of the *Evaluation Report on the Coordinated Management of Carbon Dioxide and Air Pollution in Chinese Cities (2020)* covers a total of 335 cities, including municipalities directly under the central government, all prefecture-level cities, and administrative units (except the counties directly under the governments of Henan, Hubei, and Hainan provinces, Danzhou City, Sansha City, Hong Kong, Macao, and cities in Taiwan). The evaluation objects are the changes in CO_2 emissions, air pollutants (SO_2, NO_x, and particulate matter) emissions, and air quality (concentrations of NO_2, $PM_{2.5}$, and O_3) in 2015 and 2019. The evaluation indicators include the emission reductions and emission reduction rates of CO_2 and air pollutants, the declining rate of air pollutant concentrations, local air pollutants equivalence (LAPeq), and the Air Quality Index (AQI) from 2015 to 2019. Among them, the CO_2 emission data of Chinese cities in 2015 and 2019 are from *China City Greenhouse Gases Emissions Dataset* (2015 and 2019). The evaluation only considers CO_2 emissions from energy activities, excluding the emissions from industrial processes and indirect emissions. Chinese cities' air pollutant emissions and air quality data in 2015 and 2019 are obtained from the China National Environmental Monitoring Centre.

The results show that about one-third of the cities achieved a coordinated reduction of CO_2 and major air pollutants (SO_2, NO_x, and particulate matter) from 2015 to 2019. However, the reduction rate and the proportion of cities that achieved the reduction of air pollutants were much higher than those of CO_2. Baishan, Panjin, Hebi, Karamay, Linfen, Luoyang, Pingdingshan, Kaifeng, Xinyu, and Fushun cities are ranked top 10 in terms of their comprehensive performance in reducing CO_2 and air pollutant emissions. From 2015 to 2019, 23.88% of the cities ($N = 80$) achieved the reduction of both CO_2 emissions and AQI (i.e. air quality improvement). Baishan, Panjin, Neijiang, Qitaihe, Shizuishan, Shangqiu, Haibei, Yan'an, Pingdingshan, and Fushun cities are ranked top 10 in terms of comprehensive performance in CO_2 emission reduction and air quality improvement. Cities such as Baishan, Panjin, Pingdingshan, and Fushun performed well in the overall rankings related to the coordinated management of CO_2 and air pollutant emissions and that of CO_2 and air quality. Evaluating the current status of such coordinated management in cities, summarizing experience, and identifying problems are conducive to optimizing the coordinated management of GHGs and air pollutants at the city level, and providing useful advice for researchers, planners, and policy makers to coordinate the targets of GHGs and air quality and conduct path planning.

4.1.2. *Unified accounting method of CO_2 and air pollutant emissions*

At the inventory level, studying the unified method of CO_2 and air pollutant emissions from the perspectives of data sources, inventory structure, and emission accounting can lay a sound foundation for cities to peak CO_2 emissions and meet air quality standards.

Table 2. The unification of CO_2 and air pollutant emission inventories.

Type of emission sources	Sector	GHGs			Air pollutants					After unification	Proxy factors of spatial distribution
		CO_2	CH_4	N_2O	$PM_{2.5}/PM_{10}$	NO_x	SO_2	CO	VOCs		
Mobile sources	1. Transportation									1. Transportation	1.1. Road density/class/type/length 1.2. Positioning of airports by latitude and longitude 1.3. Railway density/population 1.4. Area of rivers and territorial sea/ population 1.5. Population grid
	1.1. Road vehicles	√	√	√	√	√	√	√	√		
	1.2. Aviation	√	√	√	√	√	√	√	√		
	1.3. Railway	√	√	√	√	√	√	√	√		
	1.4. Water transportation	√	√	√	√	√	√	√	√		
	1.5. Off-road transportation	√	√	√	√	√	√	√	√		
Point sources	**2. Industrial energy**										
	2.1. Power production	√	√	√	√	√	√	√	√	2. Industrial energy	Positioning by latitude and longitude/ population grid
	2.2. Heat supply	√	√	√	√	√	√	√	√		
	2.3. Ferrous metal smelting	√	√	√	√	√	√	√	√		
	2.4. Non-ferrous metal smelting	√	√	√	√	√	√	√	√		
	2.5. Petroleum extraction	√	√	√	√	√	√	√	√		
	2.6. Petrochemical industry	√	√	√	√	√	√	√	√		
	2.7. Mining industry	√	√	√	√	√	√	√	√		
	2.8. Other biomass boilers	√	√	√	√	√	√	√	√		
	3. Industrial processes										
	3.1. Ferrous metal smelting	√	×	×	√	√	√	√	√	3. Industrial processes	Positioning by latitude and longitude
	3.2. Non-ferrous metal smelting	×	×	×	√	×	×	×	×		
	3.3. Cement production	√	×	×	√	√	√	√	√		
	3.4. Lime production	√	×	×	√	×	×	×	√		
	3.5. Flat glass production	×	×	×	√	√	√	×	√		
	3.6. Ceramic production	×	×	×	√	√	√	√	√		
	3.7. Coke production	×	×	×	√	√	√	√	√		

Table 2. (*Continued*)

Type of emission sources	Sector	GHGs			Air pollutants					After unification	Proxy factors of spatial distribution
	3.8. Natural gas production	×	√	×	×	×	×	×	√		
	3.9. Production of ethylene, benzene, and toluene	×	×	×	×	×	×	×	√		
	3.10. Sulfuric acid production	×	×	×	×	×	√	×	×		
	3.11. Nitric acid production	×	×	√	×	×	×	×	×		
	3.12. Adipic acid production	×	×	√	×	×	×	×	×		
	3.13. Calcium carbide production	√	×	×	×	×	×	×	×		
	3.14. Production of ink and fuel	×	×	×	×	×	×	×	√		
	3.15. Synthetic ammonia	×	×	×	×	×	×	√	√		
	3.16. Ethylene, polyethylene, and polyvinyl chloride	×	×	×	×	×	×	×	√		
	3.17. Manufacturing of chemical fibers	×	×	×	×	×	×	×	√		
	3.18. Paper making	×	×	×	×	×	√	×	√		
	3.19. Food manufacturing	×	×	×	×	×	×	×	√		
	3.20. Textiles	×	×	×	×	×	×	×	√		
Non-point sources	**4. Agriculture**										
	4.1. Nitrogen fertilizer use	×	×	√	×	√	×	√	×	4. Agriculture	Farmland area Positioning of farms by longitude and latitude
	4.2. Livestock and poultry farming	×	√	√	×	√	×	×	×		
	4.3. Rice fields	×	√	×	×	×	×	×	×		

Table 2. (*Continued*)

Type of emission sources	Sector	GHGs			Air pollutants					After unification	Proxy factors of spatial distribution
	5. Household										
	5.1. Household heating boilers and stoves	√	√	√	√	√	√	√	√	5. Household	Population grid
	5.2. Household biomass stoves	√	√	√	√	√	√	√	√		
	5.3. Boilers for household use	√	√	√	√	√	√	√	√		
	6. Waste disposal										
	6.1. Sewage treatment	×	√	√	×	×	×	×	×	6. Waste	Positioning by latitude and longitude
	6.2. Landfill, compost, and incineration of solid wastes	√	√	√	×	×	×	×	√		
	6.3. Flue gas denitrification	×	×	×	×	×	×	×	×		
	7. Biomass burning										
	7.1. Open combustion of biomass	√	√	√	√	√	√	√	√	7. Biomass burning	Satellite data
	8. Dust										
	8.1. Soil dust	×			√	×	×	×	×	8. Dust	8.1. Areas corresponding to different land-use types 8.2. Road density/class/type/length
	8.2. Road dust	×			√	×	×	×	×		
	8.3. Construction dust	×			√	×	×	×	×		
	8.4. Stacking dust	×			√	×	×	×	×		
	9. Solvent use										
	9.1. Printing and dyeing	×			√	×	×	×	√	9. Solvent use	9.1. Positioning by longitude and latitude

Table 2. (*Continued*)

Type of emission sources	Sector	GHGs			Air pollutants					After unification	Proxy factors of spatial distribution
	9.2. Surface coating	×			√	×	×	×	√		9.2. Positioning by longitude and latitude
	9.3. Pesticide use	×			√	×	×	×	√		9.3. Farmland area
	9.4. Asphalt pavements	×			√	×	×	×	√		9.4. Paved road length
	9.5. Timber production	×			√	×	×	×	√		9.5. Positioning by longitude and latitude
	9.6. Pharmaceutical production	×			√	×	×	×	√		9.6. Positioning by longitude and latitude
	9.7. Other solvent use	×			√	×	×	×	√		9.7. Positioning by longitude and latitude
	10. Storage and transportation										
	10.1. Oil and gas storage and transportation	×			×	×	×	×	√	10. Storage and transportation	Positioning by latitude and longitude/ road network
	11. Other emission source										
	11.1. Dining smoke	×			√	×	×	×	√	11. Other emission source	Population grid
	12. Land use										
	12.1. Land-use changes	√	√	√	×	×	×	×	√	12. Land-use change	Land-use types

From the aspect of CO_2 emission inventory, the emission sources include industrial energy, industrial process, service, agriculture, transportation, and urban and rural building. From the aspect of air pollutant emission inventory, the emission sources include transportation, industrial energy, industrial processes, agriculture, household, waste disposal, biomass burning, dust, solvent use, storage and transportation, other emission sources, and land use. It thus can be seen that there are differences in the classification of sectors between the inventories of CO_2 and air pollutant emission inventories. Using the pollutant emission scenario as the standard and the CO_2 emission inventory as its counterpart, the final results for the unification of both inventories are shown in Table 2, which helps to establish a unified accounting method and serves the compilation of an integrated inventory.

4.2. *Future prospects of synergistic governance*

The 14th Five-Year Plan period is a key stage for China to achieve the "dual targets" of peaking CO_2 and meeting air quality standards. Although most GHG and air pollutant emissions can be controlled in a coordinated manner, Chinese cities still fall short of coordinated and refined measures to control air pollutants and CO_2. At present, there are still a few studies on the synergistic relationship between CO_2 peaking and air quality at the city level. In order to have a coordinated and refined control of air pollutant emissions, air quality, and CO_2 emissions, and achieve the "dual targets", it is necessary to strengthen the research and application of a comprehensive evaluation system and boost the synergistic governance of the environment and climate. At the national level, it is suggested to focus on the spatial control of CO_2 reduction under the environmental quality constraint, and set targets for carbon reduction and coal consumption control in the BTH and YRD regions. At the city level, it is recommended to launch pilot projects for peaking CO_2 and reaching air quality standards, and develop a management system that comprises strategies, plans, policies, and monitoring systems, so as to achieve unified planning, deployment, implementation, and monitoring of air pollutants and GHGs control.

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