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Government initiatives

Analysis of the co-benefits of climate change mitigation and air pollution reduction in China

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A B S T R A C T

The unprecedented resources and energy needed to support the high growth of urbanization with the emerging issues of environmental degradation and GHG emissions is increasingly dramatic in China. A series of national and local policies have been implemented for achieving the co-benefits of reducing emissions of greenhouse gas (GHG) and air pollution for China's sustainable development. In this paper, the achievement of climate change mitigation and air pollution reduction in different sectors through implementing policies is reviewed. This paper reports on the types of policy measures that have been introduced in two cases (i.e. Tiexi District of Shenyang and Baoshan District of Shanghai) to affect air quality and energy efficiency improvements, which are then collectively examined in terms of their impacts on GHG and air pollutant emissions. Recommendations are made for achieving co-benefits effectively through the integrated approach by comprehensively concentrating on the short and long-term environmental protection and energy conservation at local and national levels based on the analysis made in the paper. The limited coordination and lack of capacity in different government bodies may be the main barriers to the implementation of a co-benefits approach. Enhancing the cooperation and capacity building could overcome these obstacles.

1. Introduction

In China, the current urban population has exceeded the rural population (i.e. 51.3%),[1] and it has kept the average growth by 3.9% since 1990 (Global Macro Economic Data, 2012). The urban population in China is expected to reach a level of 62% of the total population by 2030 (Department of Economic and Social Fares of United Nations, 2011). The urbanization in China has significantly enhanced economic development and increased the prevalence of social changes. The process of urbanization is attracting China's youth to urban centers, bringing with them increasing labor forces that assist in supporting urban structural and economic development. The contribution of urbanization to China's gross domestic product (GDP) was 61% in 2009 (National Bureau of Statistics of China, 2010). Since 1980s, China has placed increasing focus on policies that are associated with urban and economic development.

Negative outcomes of increased urbanization have emerged with the rapid urban development in China. The unprecedented amounts of resources and energy needed to support China's scale of urban growth rate is leading to increasing issues of emerging environmental degradation, an issue of China's development that needs to be tackled immediately. For instance, the large amounts of fossil fuels that are consumed in association with China's urbanization process, leads to billions of tons of greenhouse gases (GHGs) and other pollutants being emitted into the atmosphere every year, which causes climate change and air pollution. The fossil fuels that urban development heavily depends on are finite, and their reserves are concentrated to only a few countries and regions such as the Middle East and Africa, unstable political and economic situations in these regions place China's energy supply at a high risk.

According to the information from the China's Statistical Yearbook 2010 (National Bureau of Statistics of China, 2010), the total energy consumption was 3066 million tons of standard coal equivalent (2496 TWh equivalent) in 2009. With the high growth of economy, the energy consumption has increased by 13.5% between 2000 and 2009 (Fig. 1). China has become one of biggest energy consumers of oil and natural gas with the highest imports in the

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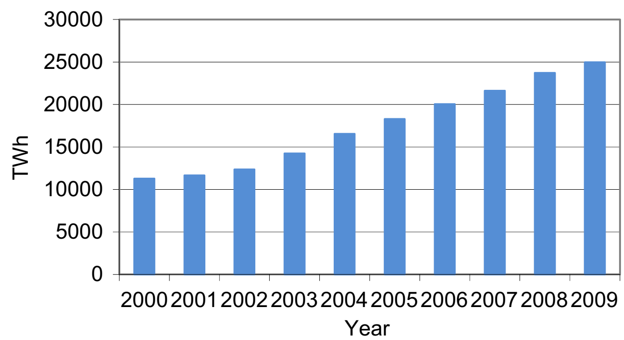

Fig. 1. The total energy consumption in China between 2000 and 2009.

world (BP, 2011). The percentage of energy use in different sectors is broken down in Fig. 2.

Coal comprises 70.4% of the total energy consumption in China in 2009 (Fig. 3) (National Bureau of Statistics of China, 2010). Because coal is the dominant energy source in China, GHG emissions and other air pollutants (e.g. SO_2, NOx, CO and particulate matter (PM)) produced by consuming fossil fuels are higher than many developed countries. For example, the generation of one kWh of electricity in China produces about 0.8 kg CO_2 (Qiu et al., 2007) which is higher than Japan (Kiko Network, 2008). Since the total energy consumption in China will continue to increase with its rapid urban growth in the following decades, reducing the energy consumption, especially the use of fossil fuels and cutting GHG and air pollutant emissions have become core national policies in order to create more sustainable development. Relevant studies carried out on China's energy conservation show that many policies and measures with the aim of reducing GHG emissions lead to a decrease in air pollution creating a co-benefit (Aunan et al., 2004). A range of energy saving policies also entail reductions in air pollution and the improvement of public heath as a co-benefit (Chen et al., 2007). This implies that climate change and air quality issues are closely linked. First and foremost, the main greenhouse gases CO_2 and the main air pollutants to a large extent stem from same sources, mainly of fossil fuels.

IPCC (2007) also clearly points out that the implementing policies of GHG emissions mitigation and energy efficiency will also have other benefits, such as reducing air pollution, achieving public heath, and improving working environment.

However, there are important differences at the temporal and spatial scales between air pollution control and climate change effects. Benefits of reducing air pollution are more certain and can be achieved quicker in the places where measures are taken while the impact of climate is a long-term and global (Swart et al., 2004; Rypdala et al., 2005). Furthermore, different focuses have been put

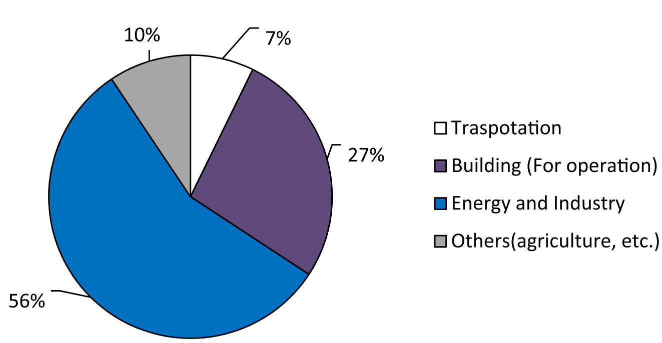

Fig. 2. Energy use in different sectors in China in 2009.

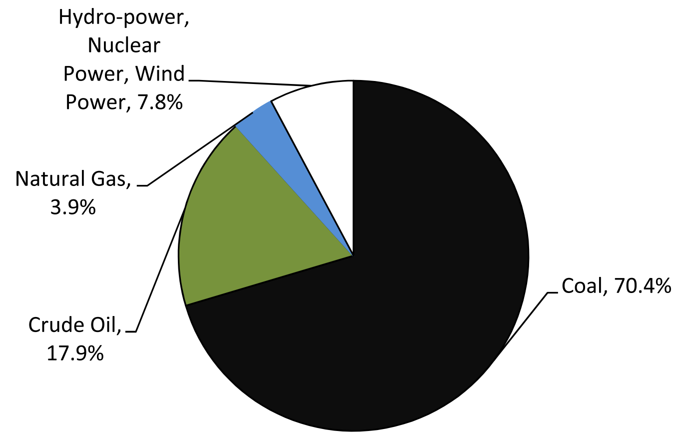

Fig. 3. The composition of total energy consumption in China in 2009.

on policies and measures of energy conservation, carbon reduction and air pollution control regarding various urban development situations and economic development levels in different places. So, the main question in this paper is how to achieve comprehensive co-benefits effectively through the approach with addressing the short and long-term goals in implementing policy measures at local and country levels in China.

2. The co-benefits approach

The "co-benefits" is a term which is increasingly being used in climate change discourse. In the field of environmental protection the term co-benefits means synergies of energy conservation and pollution reduction (reducing GHG emissions and reduce pollutants emissions). Recently, the varying use of this term in "Climate co-benefits" and "Climate and air co-impacts"(Department of Economic and Social Fares of United Nations, 2011) indicated that there are almost no agreement on assessing co-benefits with diverse methods and tools. As witnessed, different institutions and organisations have a different understanding, definition and interpretation. For instance, the co-benefits is defined by the Ministry of Environmental of Japan (MOEJ) and IPCC that co-benefits is the process of controlling GHG emissions and reducing other local emissions (e.g. SO_2, NOx, CO, and PM); on the other hand, local pollution control in the sustainable development process can also reduce or absorb CO_2 and other GHG emissions (Ministry of Environmental of Japan, 2008; IPCC, 2007). The general co-benefits definition with the context of GHG emissions mitigation, pollutants reduction, health improvement and other aspects within the scope of sustainable development can be presented in Table 1.

With the high growth of urbanization and economy, China has become the largest energy consumer in the world since 2010 (BP, 2011). And the coal dominated energy consumption lead to much higher emissions of CO_2, SO_2, NOx and PM for producing per unit of GDP than many countries. The climate in China has had many experienced and noticeable changes by increasing GHG emissions since last century (National Development and Reform Commission of China, 2007). And SO_2, CO, NOx and PM emissions made in the process of energy consumption also lead to serious regional air pollution which has huge impacts on the ecosystem and human health. The challenge of climate change, tense energy safety and unhealthy atmospheric environment make Chinese government to think the solution to these issues through a comprehensive strategy of sustainable development.

Table 1
General aspects of co-benefits in terms of the sustainable development.

Category of co-benefits		Description
Global	GHG emissions reduction	GHG emissions reduced mainly through cutting fossil fuels consumption and improving energy efficiency.
Local	Air quality improvement	Reduction of pollutants, such as SO_2, NOx, PM, CO.
	Waste management	Reduced use of primary materials; reduction of hazardous waste, waste materials; and reduced waste disposal costs. GHG emissions (e.g. CO_2, CH_4) are also reduced in the process of waste treatment.
	Water quality improvement	Reduction of pollutants in water such as COD and BOD, etc. GHG emissions (e.g. CO_2, CH_4) is also reduced in the process of water quality improvement.
	Production	Improved product quality or purity; improved equipment performance and capacity utilization; reduced process cycle times; increased production reliability; increased customer satisfaction.
	Health	Reduced medical/hospital visits, reduced lost working days, reduced acute and chronic respiratory symptoms, reduced asthma attacks, increased life expectancy.
Others		Increased facility reliability; reduced requirement and costs for the operation and maintenance of facilities. Improving the working environment (e.g. improved lighting, temperature control and air quality; reduced noise levels; reduced need for personal protective equipment; increased worker safety.)

The co-benefits discussed in this paper refer to the achievement of mitigating climate change, solving local environmental and developmental problems as well as improving public health through the implementation of energy and environmental protection policies. Some studies made in the similar research area mostly focus on qualifying the co-benefits of mitigating GHG emissions and reducing air pollutants through policies of energy conservation, climate change and air pollutant control. He et al. (2010) adopted the energy projection model, the emission estimation model, the air quality simulation model and the health benefit evaluation model for assessing the co-benefits achieved under different energy policies in China by 2030. Chen et al. (2006) forecasted the missions of CO_2 and local air pollutants in Shanghai by utilizing different energy policy scenarios in the study, and evaluated the co-benefits regarding various energy structures in different sectors between 2000 and 2020. The health benefits and socio-economic costs of CO_2 reduction related to the coal consumption in Shanxi was also evaluated in the study of Aunan et al. (2004) through six options of CO_2 reduction policy measures.

Understanding and qualifying co-benefits during the process of implementing energy-related policy measures are very important but it is just a part of story. Considering the fact that there are temporal and spatial differences between air pollutant control and climate change mitigation, the more important aspect is how to achieve the co-benefits effectively by addressing different focuses of benefits in reducing air pollutants and GHG emissions in the short and long-term development policies at local, national and international levels. So, this paper puts the concentration on reviewing an integrated co-benefits approach which contains of a series of strategic actions for delivering multiple benefits through the implementation of relevant policy measures. It explores the aspects which could significant influence the effectiveness of achievement of co-benefits (Fig. 4).

3. Implementation of the co-benefits policies in China

3.1. Legislations

China is now facing big challenges in tackling energy and environmental issues and keeping the sustainable development. China has issued some policies in recent years which focus on the energy conservation or GHG emissions reduction which lead to air pollution cutting and environment improvement. The most important national development strategy with key policies to the energy conservation and the mitigation of climate change is the national five-year plan. The first national plan which included the explicit objective of reducing energy consumption intensity was “The Eleventh Five-Year Plan (2005–2010)”. It made the goal of reducing energy consumption per unit of GDP by 20% by 2010 compared to the level of energy use in 2005. (State Council of the People’s Republic of China, 2005). In the following national plan “The Twelfth Five-Year Plan (2011–2015)” which has stricter objective to reduce carbon emissions density per unit of GDP by 17% by 2015 compared to the level of carbon emissions in 2010 in China (State Council of the People’s Republic of China, 2010). Another important national policy entitled “China’s Policies and Actions for Addressing Climate Change” was issued in November 2010 with a more ambitious objective of cutting GHG emission per unit of GDP by 40–45% by 2020 (National Development and Reform Commission of China, 2010). The National People’s Congress also approved an important law “The Energy Conservation Law of China” in October 2007, and all local energy saving policies and regulations shall be compliant to this law (Standing Committee Meeting, 2007).

In 2009, the Chinese central government issued the “China Sustainable Development Strategy Report 2009” in which the China’s low-carbon economy strategy is addressed (Wang et al., 2009). The strategy mainly contains several explicit goals of energy conservation and promoting the renewable energy with the direct co-benefits of GHG emissions and air-pollutants reduction, including:

- Reduce energy consumption per unit GDP by 20% by 2010.
- Quadruple economic growth while only doubling energy consumption between 2000 and 2020.
- Increase the share of renewable energy in total primary energy supply to 10% by 2010, and 15% by 2020.
- Increase on-grid wind capacity to 10 GW by 2010, 20 GW by 2015, and 30 GW by 2020.
- Establish 30 million square meters of solar power generation by 2020.

A series of special national policies and laws related to the economic and environmental development are mainly made by the National People’s Congress. Normally, the national energy-related policies which focus on the climate change and pollutant control are worked out and issued by ministries such as the National Reform and Development Commission and the National Environmental Protection Bureau.

There are some main energy-related policies presented in Table 2.

3.2. Implementation of policies to achieve co-benefits in different sectors

3.2.1. Energy and industry sector

The “Law of the People’s Republic of China on Energy Conservation” was amended and adopted at the 30th Meeting of the Standing Committee of the Tenth National People’s Congress of the People’s Republic of China on 28th October 28, 2007, and then went into effect on 1st April, 2008 (Standing Committee Meeting, 2007).

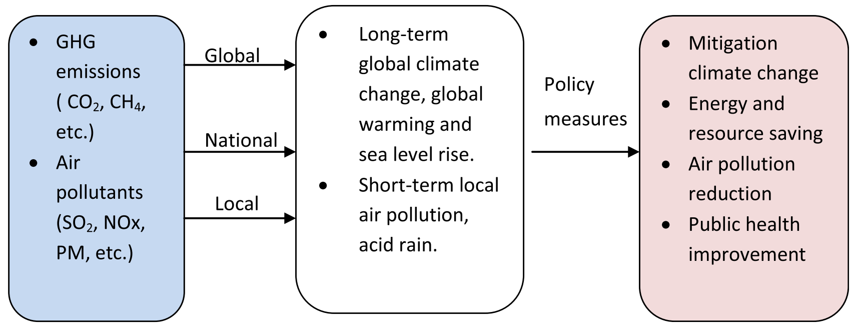

Fig. 4. Aspects contained in the co-benefits approach.

On 1st January 2006, another important law named "The People's Republic of China Renewable Energy Law (The Standing Committee of the National People's Congress of the People's Republic of China, 2005)" came into effect. It is another Chinese governmental action to reduce fossil fuel consumption and protect the environment. This is the first law to promote the development of renewable energy covering technological, managerial, financial, and research aspects, etc. The goal of the law is to increase the use of renewable fuels to 10% by 2010, and 15% by 2020. This is an ambitious objective which will have a great influence on China's energy structure and environmental protection plans.

China's Top 1000 Industrial Energy Conservation Programme aims to reduce the energy consumption of its 1000 largest industrial consumers and covers enterprises from numerous sectors (OECD et al., 2009). In 2004, this group accounted for more than 33% of China's total energy demand and 47% of industrial energy consumption; in 2006, the group was responsible for 43% of China's carbon dioxide emissions. The programme attempts to reduce carbon dioxide emissions by between 300 million and 450 million tonnes, which is the equivalent of removing 68 million to 100 million cars from the road. The Programme requires selected enterprises to reach leading domestic or international levels of energy efficiency.

In October 2007, the National Development and Reform Commission (NDRC) implemented new regulations for industry standards for bauxite mines and aluminum processing plants. The standards cover a range of elements, such as scale of production, minimum size of plants and furnaces, technology to be implemented, resource use, as well as water and energy consumption. Furthermore, the NDRC aims to reduce the nation's kiln and boiler consumption of coal by 70 million tonnes by requiring industries to use high-quality coal, renovate smaller boilers and kilns, and establish better management and operation systems. China now uses 500,000 medium-sized and small boilers with an actual efficiency of around 65%, and 90% of them are coal-burning, consuming 350 to 400 million tonnes each year (The National Development and Reform Commission, 2007).

Table 2
Main national policies with co-benefits of reducing GHG and air pollutants emissions.

Sector	Energy-related policies
Energy and industry	• Law of the People's Republic of China on Energy Conservation • The People's Republic of China Renewable Energy Law • Top 1000 Industrial Energy Conservation Programme • Regulations/standards to energy efficiency and pollutants control
Building	• Regulations on energy efficiency in civil buildings • Various building energy saving design standards • Energy efficiency retrofit in northern area district heating • Energy conservation management in government office building and large-scale public buildings
Transport	• Fuel efficiency standards for passenger cars (equivalent to Euro IV emission standards) • Promoting public transportation programme
Waste management	• Hazardous Waste Incineration Construction Specifications • Treatment of Waste Electrical and Electronic Products Specifications of Pollution Control • Landfill leachate treatment project technical specifications • Municipal wastewater treatment plant sludge treatment and disposal best available pollution control technology guidelines

3.2.2. Building sector

The Chinese Construction Ministry has more recently been renamed the Ministry of Housing and Urban and Rural Development (MOHURD) (MOHURD, 2008). A new legislation relating to energy use in civil buildings was enacted on 1st October 2008 which aims to promote energy conservation with general terms. More specific requirements relevant to energy efficiency in the building sector have been issued by China's central and local governments in a series of energy saving and efficiency standards since 1995 (Seligsohn et al., 2009a,b), such as:

- Residential building energy-efficiency design standards: heating building energy saving design standards (for New (JGJ26-95) in 1995.
- Existing heating residential building energy saving technological criterion (for refurbished buildings, JGJ129-2000) in 2000.
- Heating residential building energy saving assessment standards (JGJ132-2001) in 2001.
- Building energy saving standards saving design standards in hot summer and cold winter zone (JGJ134-2001) in 2001.
- Building energy saving design standards in hot summer and warm winter zone (JGJ75-2003) in 2003.
- Public buildings energy-efficiency design standards (GB50189-2005) in 2005.

As part of the "11th Five Year Plan", the central government began to implement China's first national building energy standard in August 2008, which requires residential, commercial and public buildings to reduce their overall energy consumption by 50% compared to 1980 levels. China also launched the Green Star Building Evaluation Standard, which sets voluntary guidelines for building construction that raises standards above the previous building code (OECD et al., 2009) (MOHURD, 2008).

3.2.3. Transport sector

The National Development and Reform Commission established mandatory fuel efficiency standards for passenger cars in 2004. In 2009, China had a fuel economy of 36.7 miles per gallon for urban vehicles (Seligsohn et al., 2009a,b). One third of air pollution come from vehicle exhaust in China, from March 2008, China's new national standards for vehicles which are equivalent to Euro IV emission standards has been issued by the Environment Protection Bureau. Excise tax rates for vehicles have been proportional to the size of car engines since 1994, with owners of larger vehicles having to pay more.

Furthermore, considering the projected growth in the number of vehicles in the future, which will significantly intensify the urban air pollution problem along with contributing to global warming, in 2002, the Ministry of Science and Technology has developed a project with support from the Global Environment Facility (GEF) (UNDP, 2009). The project aims to decrease greenhouse gas emissions and air pollution through the widespread commercial use of Fuel-Cell Buses (FCBs) in urban areas of China. During Phase I (2002–2006), "three Fuel-Cell Buses were provided to Beijing along with an FCB workshop and garage and a Hydrogen refueling station, the first of its kind in China." Phase II (2007–2010), "will 1) demonstrate the operational viability of FCBs and their refueling infrastructure by setting up FCB fleets and supportive facilities in Shanghai; 2) accumulate technical and policy knowledge for advancing commercialization of FCB technology and supply chain nationally; and 3) promote enabling environment for FCB expansion in other cities through the design of roadmap for commercialization of fuel cell buses in China." China's government has also planned to encourage the research and production of hybrid cards and electric cards in recent years.

Promoting public transportation is another strategy of Chinese government. By the end of 2009, China has 860,000 km railway, ranting second in the world, and it has over 6500 km high-speed railway, ranting first in the world. Other public transportations such as the subway, light rail and bus are developed very quickly since 1990s.

3.2.4. Waste management

China's waste water treatment capacity has improved quickly. In 2000, only 20% of wastewater was treated, the capacity of waste water treatment was 460,000 tonnes. In 2010, the rate of waste water treatment rate would be 70%, the capacity could be 3,130,000 tonnes (The National Development and Reform Commission, 2007). The solid waste treatment capacity has increased since 1990s. For example, besides the traditional disposal approach like the landfill, other measures have been adopted such as the recycling, composting, and incinerating, etc. In terms of mitigating climate change, some projects (e.g. CDM projects) were carried out for colleting methane from the landfill sites in China.

Many national and local policies to the waste management have been issued by China's central and local governments, such as "Hazardous Waste Incineration Construction Specifications", "Treatment of Waste Electrical and Electronic Products Specifications of Pollution Control", "Landfill leachate treatment project technical specifications" and "Municipal wastewater treatment plant sludge treatment and disposal best available pollution control technology guidelines", etc.

All national policies, laws and regulations introduced above can bring more or less co-benefits in cutting energy use, GHG emissions and pollution. However, in real situations, rather than most of these polices actually focus on carbon reduction and pollution separately. Normally, Chinese policy makers haven't designed and implemented them under an integrated principle of co-benefits. Some potential improvements could be made for these policies under the co-benefits principle are presented in Table 3.

Since the environmental and climate changes have become more and more serious in China, the most feasible and direct ways to generate co-benefits of GHG emissions and air pollutants reduction under the policy interventions could be in those areas/corporations with both higher pollution and emissions such as the heavy industrial areas and energy intensity corporations (e.g. power, iron and steel, and cement enterprises) (Li et al., 2012). And also if considering the differences in the GHG emissions mitigation and air pollutants control which are described in Section 1, it could be worthy to explore the implementation of co-benefits approach at the city level where the co-benefits of air pollutants control and GHG emissions reduction often happen clearly and directly. Tiexi District of Shenyang and Baoshan District of Shanghai are typical cases for analysing how the co-benefits approach working on local sustainable development in recent years through implementing energy-related policies, because:

1) It is more directly and explicitly to evaluate the co-benefits of GHG emissions mitigation and air pollutants reduction.

Table 3
Potential improvements for current policies to achieve co-benefits.

Sector	Good practices	Lessons
Energy	• Energy laws • Energy Efficiency improvement demand policies and actions from demand and supply sides • Renewable energy laws	• Improvement of legal system • Government capacity building • Encourage the investment from public and private aspects
Transport	• Promotion of public transport • Encouragement to electrical cars • Strict vehicle exhaust regulations • Strict vehicle measures • Promotion of bicycle using	• More investment in the transport infrastructure • More sound policies and laws • More Tax or financial measures
Buildings	• Land reservation laws • Regulations to energy efficiency in buildings • Energy saving technologies in the building sector	• More sound regulations and supervisors needed to the land-use • Good design to land use • More updated and sound regulations needed to energy saving activities in buildings • Large commercial and public buildings should be addressed in cities for reducing energy consumption
Waste management	• Many policies and regulations have been issued by central and local governments • Rate of waste water and solid waste treatment is increasing. • Adoption of CDM activities to reduce the environmental impacts from waste treatment • Investment, especially from private investment to the waste treatment sector increases • More new and advanced technologies are used	• Need to strengthen the supervision and monitor • More sound policies and regulations are needed

2) There is a good data availability and accessibility at city level.
3) Two cases have typical characters of city transferring during the process of urbanization in China, i.e. from traditional heavy industrial districts to modern multi-service districts. The experiences of achieving co-benefits from two cases could be reproduced by other Chinese cities.
4) Cumulative GHG emissions and air pollutants reduced in Tiexi, Baoshan and other Chinese cities can led to achieve the environmental and economic benefits not only at local level, but also at national and global levels.

3.3. Case 1: Tiexi District, Shenyang

Shenyang city is the capital of Liaoning province and the important center for economy, culture, transportation and business in the northeast China. The energy consumption of Shenyang is projected to reach 55 million ton standard coal in 2015, which would cause massive emission of air pollutants such as SO_x, NO_x and PM and greenhouse gases especially CO_2 emissions (Shenyang Statistical Bureau, 2010). In Shenyang, the major air pollution sources and GHG emissions are from coal-fired energy consumption (Zhang et al., 2010). Tiexi district, which was regarded as famous industrial base in China located in the southwest of central Shenyang city. Its area is 39.3 km^2, its population was 0.85 million and its GDP was 17 RMB billion (USD 2.7 billion) in 2009 (Shenyang Statistical Bureau, 2010). As an industrial base, the development of Tiexi district was primarily depended on the heavily industry with high energy consumption and over 60% of air pollutants and CO_2 emissions are made by industries. Facing the serious environmental pollution such as air pollution, the local government has issued the policies to deal with the environmental problems.

In the period of between 2005 and 2009, Tiexi District government have made and implemented some local policy measures which comply with national polices shown in Table 2 to control air pollutants and reduce energy consumption. Basically, three main categories of policies measures have been carried out in Tiexi District for achieving co-benefits of reducing GHG emissions and air pollutants (Table 4).

After adopting structural emissions reduction measure, energy efficiency improvement and desulfurization measures, and offset approach, the overall CO_2 and air pollutants emissions have been reduced significantly between 2005 and 2009 through implementing the policy measures (Fig. 5).

3.4. Case 2: Baoshan District, Shanghai

Shanghai is located in eastern China and it is one of largest cities with a population of 1.91 million in 2010 (Shanghai Bureau of Statistics, 2011). Baoshan District is one of 18 districts of Shanghai with a population of 1.9 million. It is located in north Shanghai with the area of 293 km^2 (Baoshan Bureau of Statistics, 2011). Baoshan District has become an industry base for Shanghai since 1980s. It is an important industry center for iron and steel production, shipping containers manufacture and energy supply. The industry sector contributes over 60% of whole GDP of Baoshan District (Baoshan Bureau of Statistics, 2011). In this sector including enterprises of iron, steel, container and chemical products manufacturing, and power producing with very high energy intensity. The industries consumed 27 million tons of standard coal, equivalent to the emissions of 18 million tons of CO_2 equivalent (CO_2e) in 2010 (Baoshan Bureau of Statistics, 2011). The raw coal and coke were two main sources in Baoshan share 81.2% and 6.7% of the total energy consumption respectively (Baoshan Bureau of Statistics, 2011). Heavily relying on the fossil fuels, special coal makes the huge amount of GHG and air-pollutants emissions in this district.

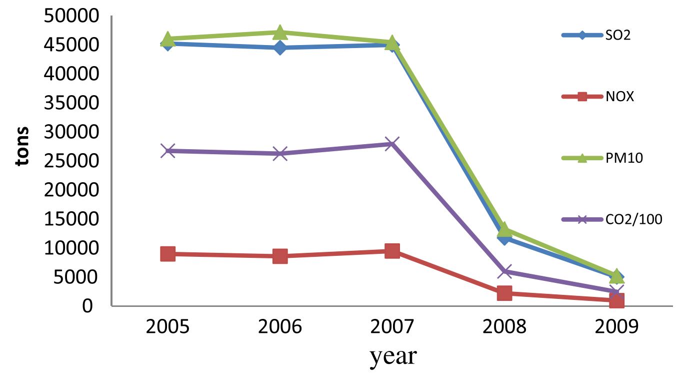

Fig. 5. CO_2 and air pollutant emissions in Tiexi district.

According to the reports from the Baoshan District Environmental Protection Bureau (2011), the main air pollutants emissions from the industry and transport sectors in 2010 are presented in Table 5. And over 86% of air pollutants are from industrial sources, the same situation as the Teixi case discussed above.

Over 50% of total carbon and air pollutants emissions in Shanghai are contributed by Baoshan District. For instance, emissions of SO_2 and NOx accounted for 21.7% and 31.2% respectively for the whole Shanghai are from Baoshan District in 2010 (Baoshan District Environmental Protection Bureau, 2011).

In order to achieve co-benefits of reduction of GHG and air pollutants emissions not only for Baoshan, but also for the whole Shanghai city, relevant policies have been carried out in Baoshan. Each district in Shanghai is guided by the national policies (e.g. the national five-year plan) for the energy conservation and GHG emissions reduction. For Baoshan District with the high energy-intensity and heavy pollution industry sector, more local efforts have been made to achieve co-benefits. Baoshan District government has issued its own "Eleventh Five-year Plan" based on its local realities. Furthermore, the Environmental Protection Bureau of Baoshan has worked out the Fourth Three-year Environmental Action Plan (2009–2011) with the objectives of reduce the energy use for per unit of GDP by 25%, SO_2 emissions by 10% and the

Table 4
Policy measures of reducing GHG emissions and air pollutants in Tiexi District, Shenyang.

Policy measure	Description	Air pollutant reduction	GHG reduction	Co-benefits
Structural emissions reduction	Relocation or closure of enterprises with high pollution and high energy consumption.	SO_x, NO_x, PM_{10}	CO_2	Yes
Energy efficiency improvement and desulfurization	Centralized heating system	SO_x, NO_x, PM_{10}	CO_2	Yes
	Demolish small heating boilers	SO_x, NO_x, PM_{10}	CO_2	Yes
	Geothermal heating system for household	SO_x, NO_x, PM_{10}	CO_2	Yes
Offset approach	Desulfurize boilers	SO_x	–	–
	Planting trees	SO_x, NO_x, PM_{10}	CO_2	Yes
	Making urban greenbelts	SO_x, NO_x, PM_{10}	CO_2	Yes

Table 5
Major air pollutants in Baoshan in 2010.

Main pollution	Industry	Transport	Proportion of industrial sources (%)
Waste gas (10^8 m^3)	5901	–	–
SO_2 (ton)	5,5844	83.0	99.9
NOx (ton)	123,998	4349	96.6
Flue dust (ton)	16,492	–	–
Dust (ton)	16,735	10,554	61.3

amount of dust by 10% (Baoshan District Environmental Protection Bureau, 2012).

Similar measures like Tiexi in Shenyang have also been implemented in Baoshan, such as the structural, technical pollutant emissions reduction and project management measures. From 2005 to 2010, the co-benefits of carbon intensity and air pollutants have been reduced through implementing the local policy measures in Baoshan District. For example, the energy consumption per unit of GDP was declined by 26.7% in 2010 compared to the level of 2005. More than 200 enterprises have improved the energy efficiency and reduced air pollutants under the structural and technical emissions reduction measures. Especially the air pollution in whole region of Baoshan District has been decreased and the environment has been improved by adopting the integrated management measures such as the enterprise pollution Index and the colored grid management. Overall SO_2, NOx, and dust emissions reduction in Baoshan between 2005 and 2010 is shown in Fig. 6. SO_2 emissions were reduced by 35.1%, dustfall and dust were decreased by 2.8% and 1.3% respectively between 2005 and 2010. However, NOx emissions increased by 2.7% because of increasing emissions from the transport sector.

Because spatial and temporal differences existing in the activities of cutting GHG emissions and air pollutants, the air pollution benefits are quicker and more certain to be achieved while the benefits of GHG emissions reduction is long-term and uncertain. Therefore in Chinese local places like Baoshan, more attention has been put in polices of mitigating air pollutants rather than carbon emissions. And there is only an objective to decrease the carbon intensity but no explicit GHG emissions reduction goals in energy-related polices implemented by Baoshan government. This is the reason that even the carbon intensity has been reduced in recent years, CO_2 emissions in Baoshan in 2010 (i.e. 873,232 tons) was still increased by 17.8% compared to the level of CO_2 emissions in 2009 (Shanghai Baoshan Statistics Yearbook, 2011).

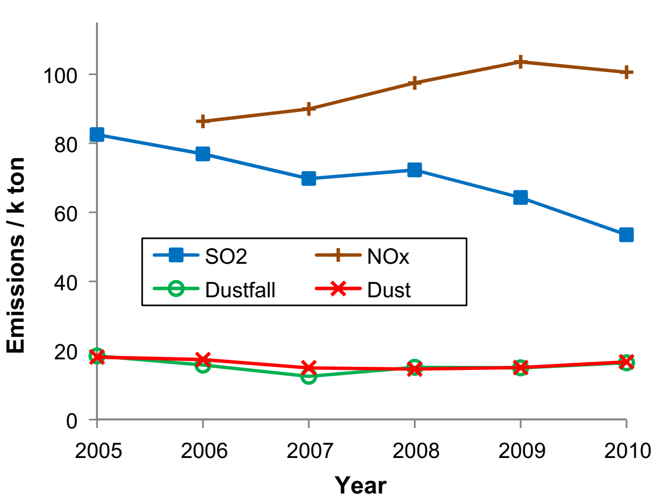

Fig. 6. Air pollutant emissions in Baoshan between 2005 and 2010.

4. Discussions and conclusions

Based on the analysis made above and the results from the studies presented in Sections 1 and 2, it is clear that energy-related policy measures resulting in GHG emissions mitigation also have other benefits of air pollutants reduction. For developing countries such as China with the increasing demand of energy for supporting its high growth of urbanization and economy, the co-benefits achieved will be larger than other developed countries (Darby and Kinney, 2010). Relevant methodologies and quantified analysis have been made in some studies which focus on the co-benefits generated by certain policy interventions in China. The results show that different scope and degree of co-benefits can be delivered under policy scenarios which are formed based on local realities (e.g. urban development, energy and environmental situations) (Chen et al., 2006; He et al., 2010; Dolf and Chen, 2001).

However, considering the spatial and temporal differences existing in energy-related climate mitigation and air pollution control policies, in order to achieve the sustainable development objective established in the China's national development strategies (e.g. the Five-Year Plan), more attention should be put on how to achieve the co-benefits effectively through an integrated approach with addressing various aspects of GHG and air pollutants emissions reduction simultaneously. According to the assessment made to two case studies above, several points need to be highlighted to the co-benefits approach which has already been implemented in China.

- Generally, climate change mitigation is a long-term process which needs more national and global efforts. However, the impact of air pollution is more certain and can be controlled easier and quicker in local places. It is understandable that the local air pollutants reduction policies have received more attention by the local governments in China, such as the Three-Year Environmental Action Plan and the Air Pollution Control Act in Baoshan. In both case studies, our study shows that GHG emissions are often treated as subsidiary benefits during the process of reducing air pollutants. Contrarily, the national policies with the aim of long-term sustainable development such as the Five-year Plan, China's Policies and Actions for Addressing Climate Change, and other energy saving and environmental protection policies (Table 2) often put the same weight on the GHG emissions and air pollution control. Therefore, an integrated co-benefits approach should address the short and long-term objectives at both local and national levels simultaneously.
- The structural emissions reduction policy has been implemented in Baoshan and Tiexi and achieved remarkable local co-benefits. In Teixi case, for instance, around 90% of CO_2 and air pollutants emissions were reduced by moving 744 enterprises from Tiexi District to Yuhong District. However, the "leakage" emissions of GHG and air pollutants from Yuhong Distric where the displaced enterprises are located are overlooked. The overall co-benefits cannot be generated because of this kind of leakage emissions are ignored. The co-benefits approach is also required to address all GHG and air pollutant emissions through the implementation of polices in different places within the whole project region.
- The public health improvement is an important aspect for achieving comprehensive co-benefits in the process of urban development. $PM_{2.5}$ refers to the fine particulate matter measuring 2.5 microns or less in diameter, which have the ability to penetrate human lung and blood tissue and can lead to asthma, cardiovascular disease and cancer. $PM_{2.5}$ has only become a focus of public health and disclosed publicly in some China's cities since 2011 (Hsu, 2012). However, in current

policies of Tiexi, only the index of PM_{10} are included. And in the Baoshan case, the only outdated indexes of dust fall and dust are measured. New policy measures for addressing $PM_{2.5}$ critically needs to be considered in the co-benefits approach.

- The co-benefits approach may end up with the barrier of limited coordination and cooperation between government bodies and divisions and thereby prevent the development and implementation of integrated policies to co-benefits. In most local governments in China, the Environmental Protection Bureau is responsible for air pollution control, and the Reform and Development Commission is responsible for the energy conservation. Lack of coordination between different government agencies may make less effectiveness or even conflicts in achieving co-benefits. The lack of coordination and collaboration in the national and local governments could also make the achievement of co-benefits in difficulties. Another important aspect is also needed to be addressed for Chinese policy makers: the climate change and air pollution are not only local and regional issues, but also global problems. The international collaborations are necessary for achieving wider and bigger co-benefits. Therefore, in order to overcome the barriers, several aspects must be addressed in the integrated co-benefits approach, the effective coordination and integrated actions need to be promoted in government agencies, such as an inter-government committee at local and national levels could be established for facilitating cooperation among government bodies; and more collaborations on efforts of climate change mitigations and air pollution control at international level should be encouraged as well, such as the clean development mechanism (CDM) under the Kyoto Protocol is a possible example for achieving co-benefits globally.

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