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Assessing the environmental sustainability with a co-benefits approach: a study of industrial sector in Baoshan District in Shanghai

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ABSTRACT

It is often difficult to determine the effects of policies at a sectoral level in the overlapping domains of pollution control and energy conservation, making it difficult to consider co-benefits of energy conservation and air pollution reduction and tensions. In China, the industry sector contributes much more carbon and pollution emissions than other sectors. In this paper, Baoshan District (BSD), one of the most important industrial zones in the Shanghai metropolis, is used as a case study to illustrate the situation and to provide information to assess the effectiveness of environmental sustainable development policies in industries. The policies resulting from China's Eleventh Five-year Plan (FYP) are considered at the level of BSD. In particular, the result of implementing local policies of air pollution control and energy are analysed at BSD. Three indicator systems are adopted for quantitatively and qualitatively evaluating energy saving and air pollution reduction achieved by technical, structural and management measures in industrial enterprises of BSD. Analysis made in the paper shows that the co-benefits of pollution cutting and energy conservation have been achieved at certain scopes and degrees in the industry sector in BSD, e.g. SO_2 and Particulate Matter (PM) were reduced by 35.1% and 7.7% respectively, and the energy density was cut by 26.7%. Due to existing barriers of the lack of co-planning and co-operations in the process of designing and implementing the policies, and the overlooking the leakage of emissions in the whole project area, the overall co-benefits cannot be achieved effectively in BSD. Recommendations are made for future detailed studies of this or similar districts to develop an indicator system of co-benefits to help demonstrate the advantages of joint planning and policies for co-benefits.

1. Introduction

The impact of humans on their environment has been shown to make a discernable contribution to climate change and the sustainable development (IPCC, 2007), and the world is working on mitigating these effects. Thus improving the sustainable development with the context of reducing green house gas (GHG) emissions and pollution has been drawn more attention of both researchers and policy-makers (Jiang et al., 2013). Since the consensus has been accepted that the climate change is mainly caused by human activities especially by burning fossil fuels, a fact is also clear that pollutions particularly most air pollutants (e.g. SO_2, NOx, CO and particulate matter (PM)) are by-products of consuming fossil fuels. Co-benefits achieved from mitigating climate change, solving environmental and developmental problems as well as improving public health through the implementation of environmental protection and energy policies is the focus of this paper.

The Intergovernmental Panel on Climate Change (IPCC) distinguished the co-benefits, or intended positive side effects, of a policy from the ancillary benefits, or unintended positive side effects, in the Fourth Assessment Report (AR4), the term "co-benefits" has received significant attention in climate change discourse worldwide. The Clean Air Initiative for Asian Cities (CAI-Asia) has defined the concept of "co-benefits" as the various benefits that can be provided by managing climate change and air pollution (CAI-Asia, 2011). The varied use of this term in "climate co-benefits" and "climate and air co-impacts" (Smith and Haigler, 2008) indicates

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that there is no agreement on the assessment of co-benefits through diverse methods and tools. Different institutions and organizations have different understandings, definitions and interpretations. In the field of environmental protection, the term co-benefits means synergies of energy conservation and pollution reduction (mitigating GHG emissions and reducing pollution emissions). In this context, it is assumed that ecological processes can be achieved with energy-saving processes that match the demands of economic development. Based on a literature review, we define co-benefits as the achievements of mitigating climate change and solving local environmental and developmental problems through the simultaneous implementation of policies and strategies.

With ongoing trends toward deteriorating environmental conditions during socioeconomic growth, developing countries such as China have recognized that promoting the implementation of the co-benefits approach can lead to both environmental pollution control and GHG emission reduction (Japanese Overseas Environmental Cooperation Center, 2008). China is currently developing policies to encourage co-benefits in research and technology (Li et al., 2011), such as coal moisture control (CMC) in the coal, iron and steel industries; technical analysis of the synergistic effect of the power industry; and fuel conversion technology co-benefits analysis. He et al. (2010) emphasize that the co-benefits achieved through implementing energy policies at national level. Aunan et al. (2007) analyses the pollution reduction, public health and increasing agricultural yields by adopting the climate policy in China. A similar research also shows that the health and socioeconomic benefits achieved through CO_2-reducing options/policies at province level in China (Aunan et al., 2004). Furthermore, Cao et al. (2008) use “Top-down” and “Bottom-up” modeling analysis to quantify the co-benefits caused by the Chinese national GHG mitigation policies, and point out that the financial measures (e.g. the fuel tax and the carbon tax) could be an important part of policies with more co-benefits achieved. Lu et al. (2010) predicted that China could have an annual reduction in SO_2 emissions of 33 million tons, thus significantly decreasing deaths due to air pollution and related social costs. According to a study undertaken by the Shanghai Academy of Environmental Sciences (SAES), synergistic approaches in Shanghai, including improving air quality and reducing GHGs, would significantly reduce the risk of public exposure to air pollution, thus reducing the number of potential deaths. In particular, reducing the concentration of PM in the air would prevent 647 to 5472 adolescents from dying of associated illnesses in 2010 and from 1265 to 11,130 from dying in 2020 (Hu et al., 2004). Thus, it is projected that a significant decline in PM would result in social and economic benefits that would reach 113–950 million US dollars (in 2000 constant prices) in 2010 and 327–2884 million US dollars in 2020 (Chen et al., 2007). These studies clearly show that China has great potential to achieve co-benefits and a coordinated consideration of resource conservation, environmental protection and cost reduction.

Considering a half of population is in cities and the urbanization develops very quickly in recent decades in China (National Bureau of Statistics of China, 2012) and more than 70% of primary energy and sources is consumed by industries in supporting the urban growth in China (The UN Population Division, 2011), achieving the environmental sustainability in the industry sector is a key objective in China's national development strategy. However, few current studies have paid attention on the co-benefits at the city and industry level in China, especially for those urban industrial districts with high carbon and pollution emission density, such as Tiexi in Shenyang and Baoshan District (BSD) in Shanghai.

Therefore, BSD of the Shanghai metropolis is taken as a case study in this research. The focus is put on assessing the co-benefits achieved by implementing energy conservation and pollution control measures under the local policies, discussing the existing barriers, and emphasizing the cooperation and integration of measures in gaining co-benefits in the BSD. The recommendations are given for further study and evaluating the effectiveness of environmental sustainability in the BSD by a co-benefits indicator system.

2. Policy review of climate change and air quality in BSD

The Chinese government has set a target of a 40–45% reduction in GHG emissions per unit of gross domestic product (GDP) by 2020, setting 2005 as the base year (The Central Government of the People's Republic of China, 2009). In 2005, China formulated the National Economic and Social Development Eleventh Five-Year Plan (FYP) and the National Environmental Protection Eleventh FYP from 2006 to 2010 (Ministry of Environmental Protection of the People's Republic of China, 2008), which state that during the period of the Eleventh FYP, energy consumption per unit of GDP will be reduced by 20%, and discharges of emissions of major pollutants will be reduced by 10% by 2010 compared to the level of 2005. BSD is one of the most important industrial centers for steel, shipping containers, and the export of items for the energy and port sectors in Shanghai. The intensive industrial activities in BSD, such as iron and steel production and thermal power generation by burning fossil fuels, account for most of the air pollution and GHG contributions (Baoshan Government, 2009). The industry sector of the BSD is a major sector that accounts for more than 60% of the district's GDP contribution (National Bureau of Statistics of Shanghai, 2010). Important enterprises in this sector include the Baosteel Group Corporation, the Huaneng Power International Corporation (which is one of the largest listed power producers in China) and a large number of chemical industries. Not surprisingly, these industries generate over half the total GHGs and air pollution of Shanghai, which has resulted in complaints from residents (Baoshan District Environmental Protection Bureau, 2011). In the Eleventh FYP, the industry sector of the BSD has been identified as a priority area for intervention. The aim of this plan is to maintain stable industrial economy growth while simultaneously reducing the intensity of industrial energy use and the emission of pollutants through structural, technical and management approaches (Baoshan Government, 2009).

Many of the industries located in Baoshan are energy intensive, with a predominance of coal-based energy source which makes the consumption of per unit of energy in the BSD emit higher GHG emissions and other air pollutions (e.g. SO_2 and NOx) than other energy sources. Fig. 1 shows the relative amounts of the fuel types

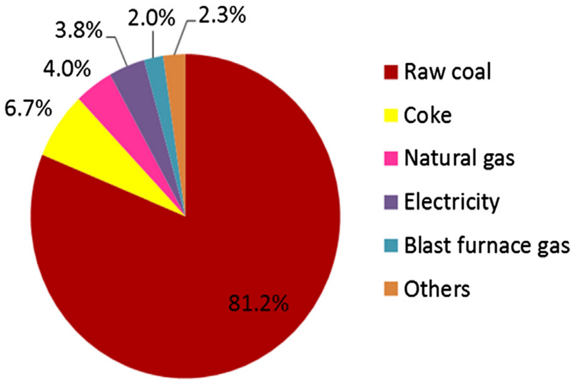


Fig. 1. Types and shares of industrial energy consumption in BSD in 2010.

used (National Bureau of Statistics of Shanghai, 2010). Coal and coke are the main sources of consumption, with a synthesized energy consumption of 81.2% and 6.7%, respectively. In 2010, the industrial energy required was 27 million tons of standard coal (tce), which is equivalent to 18 million tons of CO_2 emissions. In present energy use categories, a total of 17 million tons of tce were used as a direct energy source, accounting for 64.1% of the total industrial energy consumption. The energy consumption of the key industries in this region, such as iron and steel smelting, thermal power, non-ferrous metal smelting, and gas production/supply, account for energy consumption of 78.0%, 14.6%, 0.3% and 0.3% respectively (Baoshan Statistic Bureau, 2011; Baoshan Development and Reform Commission, 2010).

The BSD Environmental Protection Bureau developed the Eleventh FYP for Environmental Protection in the BSD, which was implemented via the Three-Year Action Plan (TYAP) for BSD Environmental Protection based on the local realities. The TYAP required the achievement of the goals of 25% energy saving and, 10% SO_2 emission decrease per unit of GDP, and a 10 ton/km^2 reduction in the amount of PM discharge in 2010 compared with the level of 2005 (Baoshan Government, 2009). Policies and regulations included special monitoring and evaluation measures which were especially implemented in the industrial sector. Table 1 provides a brief introduction to the interventions related to energy saving and pollution reduction in BSD.

The BSD Environmental Protection Bureau is the main local authority for air pollution control. Another important official agency, the BSD Development and Reform Commission is responsible for the energy conservation and GHG emissions reduction. These different agencies imply that, to some extent, pollution control and climate change mitigation in the BSD are considered separately, and the association between the two is not fully clear. For example, energy saving may not be the most important factor in policies of the Environmental Protection Bureau. Similarly, the pollution abatement may not be the priority of policies from the Development and Reform Commission. Thus, it is crucial to investigate the industry sector of the BSD and to provide essential information to assess the effectiveness of co-benefits achieved by implementing policies.

3. Methodology

3.1. Research framework

The study assesses the energy conservation and air pollution reduction through the implementation of policies under the local policies in the industry sector of BSD mainly in the Eleventh FYP (i.e. between 2006 and 2010). The focus of the research is put on two aspects: i) energy consumption and carbon emissions and ii) air pollution. Three kinds of measures addressed in the paper include: i) structural measures (e.g. relocating and closing high emission intensity enterprises), ii) technical measures (e.g. adopting low energy, low carbon and clean technologies), and iii) management measures (e.g. improving regulations, strengthening monitoring and supervision, and enhancing the capacity building). More detailed description to these three measures is given and the analysis is made subsequently for evaluating the effect of policy implementation to the air pollution reduction and energy saving. Existing barriers are discussed based on outcomes of analysis, and a co-benefits indication system is proposed to overcome constrains of current index systems for assessing the effectiveness of co-benefits in the BSD and other Chinese cities. A research framework to this study is shown in Fig. 2.

Table 1
Interventions of reducing pollutants and energy conservation/GHG emissions in BSD.

Item	Pollution reduction	Energy Conservation/GHG emissions reduction
Policies & Regulations	● The Eleventh FYP for BSD Environmental Protection ● Three-Year Action Plan for BSD Environmental Protection ● The Eleventh FYP for BSD Industrial Development and Plan. ● Local Regulations for Collection ● Utilization and Management of Pollution Emissions Charges ● Air Pollution Control Act of People's Republic of China ● Environmental Administrative Penalties.	● BSD Economic And Social Development Eleventh Five Year Plan ● Shanghai Industrial Energy Conservation and Consumption Debasement Assessment Scheme ● Practical Scheme of Shanghai Enterprises Energy Saving Action.
Economic/Market-based/ Fiscal Incentives	● Investment of Environmental Protection Accounts for 3% of Annual Financial Expenditure of BSD ● Special Funds for Environmental Management ● The "green credit" policy	/
Management measures	● Monitoring, Supervision and Management Measures ● The color grade environmental management ● Enterprise Differentiation Management ● Contract Management for Large Enterprises. ● Capacity building, e.g. establishing national secondary environmental monitoring Stations, environmental monitoring and control centers and automatic air monitoring sub-stations.	● Energy Audit and Supervision; color Grade Energy Management Regulations ● Energy Management Contract Regulations ● Increasing Laboratory Equipments Plan ● Recruiting Top Talents Plan ● Improving the Level of Information Technology for Research and Monitoring.
Structural measures	● Relocating high emission intensity enterprises ● Closing high emission intensity enterprises	● Relocating high energy intensity enterprises ● Closing high energy intensity
Technical measures	● Desulfurization technologies ● Denitrification technologies ● PM elimination technologies	● Energy saving technologies ● Improve energy efficiency

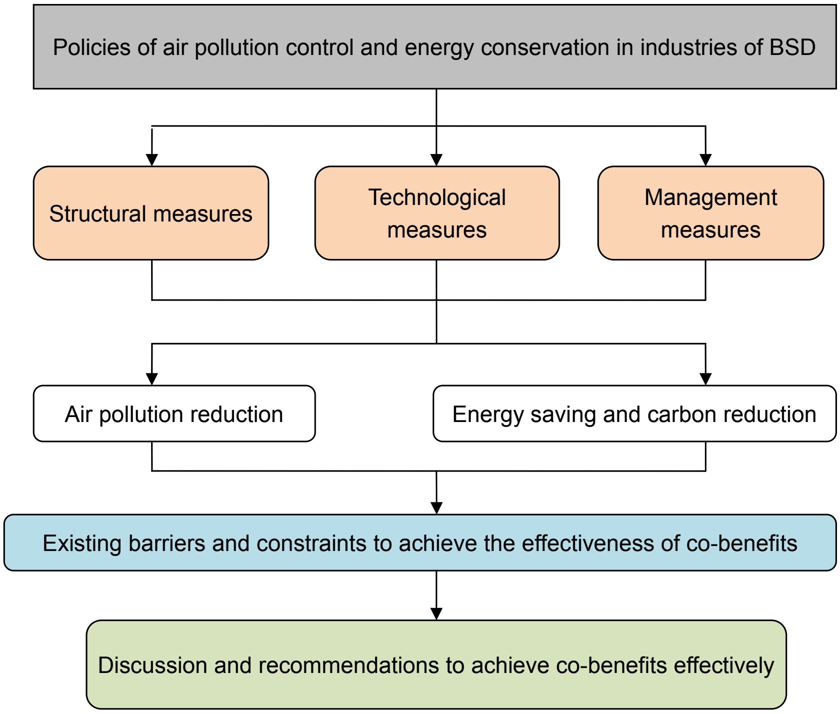


Fig. 2. The research framework.

3.2. Combined quantitative and qualitative methods

A mixture of both quantitative and qualitative methods is adopted in the study. The qualitative method is a way to understand energy saving and air pollution control policies in China and BSD firstly through the literature review. After investigating the implementation of three measures (i.e. structural, technical, and management measures) in BSD, the situation of carbon and air pollutants emissions and problems to the environmental sustainability in BSD are worked out. Based on the result of qualified analysis, the research objective, questions and the framework are formed reasonably. The quantitative method is to analyse the physical data of energy consumption, carbon and air pollution emissions. Data from over 500 representative enterprises in the BSD are selected in this study.

By using the selected data, an analysis is conducted to assess the achievement of air pollution control and energy conservation through the policy measures undertaken in the BSD. A basic equation is adopted in the study for calculating energy and pollution reduction (including CO_2 emission reduction), it is:

$$R = R_{structural} + R_{technical} + R_{management} \tag{1}$$

where R is the total reduction of energy use or pollution emissions. $Rstructural$ is the reduction due to structural measures. $Rtechnical$ is the reduction due to technical measures. $Rmanagement$ is the reduction due to management measures.

For calculating each category of reduction by a certain measure in industries, equations are given below:

$$R_{structural} = \sum_{i=1}^{n} Ri1 + \sum_{j=1}^{n} Rj2 \tag{2}$$

where $Ri1$ is the reduction made by relocating the ith enterprise and $Rj2$ is the reduction made by closing the jth enterprise.

$$\mathrm{R}_{\mathrm{technical}} = \sum_{i=1}^{n} Rit1 + \sum_{j=1}^{n} Rjt2 + \sum_{k=1}^{n} Rk3 + \ldots \sum_{o=1}^{n} Rotn \tag{3}$$

Where $Rit1$ is the reduction made through the first technical measure utilized by the ith enterprise. $Rjt2$, $Rkt3$ and $Rotn$ are the reduction made through other technical measures by the jth, kth and oth enterprises.

$$\mathrm{R}_{\mathrm{management}} = \sum_{i=1}^{n} Rim1 + \sum_{j=1}^{n} Rjm2 + \sum_{k=1}^{n} Rkm3 + \ldots \sum_{o=1}^{n} Romn \tag{4}$$

Where $Rim1$ is the reduction made through the first management measure utilized by the ith enterprise. $Rjm2$, $Rkm3$ and $Romn$ are the reduction made through other management measures by the jth, kth and oth enterprises.

3.3. Indicator systems

The indicator system is an effective way for making quantitative or qualitative analysis in understanding social, environmental, economic, institutional and spatial development (Pires and Fidélis, 2015). Mascarenhas et al. (2015) point out that the indicator systems can be suited for monitoring and investigating the results of policy implementation and determining the applicability or effectiveness of policies at local level. The literature review shows that there are few co-benefits indicator systems have been developed for measuring co-benefits of carbon reduction and air pollution control. The focus of this study is on policies of energy conservation and air pollution control and exploring the situation of environmental sustainability achieved in the industry sector in BSD. In order to well understanding the energy saving and air pollution reduction after the implementation of the measures in different enterprises in the BSD, three indicator systems designed for motoring the energy use and air pollution are discussed in the paper. These indicator systems are:

- According to the 3rd Three-year Plan of Environmental Action issued by BSD Environmental Protection Bureau, there are five grades of pollution (i.e. the good environment, standard/qualified environment, light pollution, medium pollution and heavy pollution) are defined (Hongkou, 2010). The Regional Pollution Index (RPI) is a geographic grid-based pollution index method, which is utilized in assessing the pollution situations and the local management improvement to pollution control in the industrial area in BSD. A total of 150 colored grids are designed for the area and each of grid is given a serial code (e.g. LJ-1-1, GC-1-2, DC-3-1). Differently colored indexes represent the different levels of pollution in the project area. Green color indicates a good environment, yellow color indicates a qualified environment, and orange, brawn, red and black colors indicate grades of light, medium, heavy pollutions respectively.
- The Enterprise Pollution Index (EPI) is a method for indicating and assessing the improvement of pollution emission intensity through management measures in enterprise in BSD (Baoshan District Government, 2006). 330 enterprises that contributed 95% of total pollution emissions in BSD between 2006 and 2009 (Baoshan District Environmental Protection Bureau, 2011) are selected for making the analysis by using EPI. Before 2006, 30 enterprises (E30) with a high level of pollution emission intensity were marked black enterprises; 100 enterprises (E100) with a medium level of pollution intensity were marked red enterprises; and the remaining 200 enterprises (E200) with a low level of pollution intensity were marked green. In order to make a quantified comparison to the management improvement in 330 main pollution contributors in BSD, the indexes ranged from 1000 to 7000 are designed under EPI system for indicating different levels of management improvement to pollution control in 330 enterprises (Baoshan District Environmental Protection Bureau, 2006a,b). The index of 1000 indicates the enterprises with the excellent pollution control management, and the index of 7000 indicates the worst environmental management to the pollution control.
- The Colored Energy Management Index (CEMI) is a method for presenting and comparing the levels of energy efficiency (i.e. the energy consumption for producing per unit value of CNY10,000 production) in enterprises. Enterprises with the best, good, medium, bad and the worst energy efficiency are marked as green, yellow, orange, red and black enterprises respectively (Shanghai Municipal Development and Reform Commission, 2010). 500 enterprises with the annual energy consumption over 1000 tce in BSD are chosen as research samples for making qualified and quantified analysis of the energy efficiency changes in the study between 2007 and 2009.

3.4. Data sources

Main sources of data on energy consumption and air pollution are from databases of the Baoshan District Environmental Protection Bureau, the Baoshan Statistics Bureau and the Baoshan Development and Reform Commission. More detailed quantitative data, such as energy use and SO_2 emissions in specific enterprises such as Baosteel Group Corporation and Huaneng Power International Corporation are collected directly from their energy management departments. In order to obtain qualitative data on policies, regulations and management, interviews were undertaken with government officials, senior managers, engineers, technicians, and normal staff in 75 enterprises and the local governmental divisions in 2012. Approximately 100 questionnaires related to the measures of air pollution control and energy consumption reduction were used in the interviews. In the process of quantified assessment, data from over 500 representative enterprises are selected as research samples in the study as well.

4. Results

4.1. Air pollution from the industry sector in BSD

Based on the analysis made on the data from the Baoshan Environmental Protection Bureau and the Baoshan Environmental Monitoring Station, the results show that the air pollutants in BSD were mainly from the industry and transport sectors (Table 2) in 2010 (Baoshan District Environmental Protection Bureau, 2011). The industry sector shared 89.5% of total air pollution in BSD. Air pollutants were mainly made by coal fired power plant boilers, industrial boilers, industrial furnaces and exhaust from production processes. Especially, more than half of SO_2, NO_x and PM emissions in BSD were from the steel and iron enterprises and the power plants. Moreover, 21.7% of total SO_2 and 31.2% of total NO_x emissions in the urban area of Shanghai were contributed by the industry sector of BSD in 2010 (Baoshan District Environmental Protection Bureau, 2011).

During the Eleventh FYP (2006–2010), the BSD developed its local three-year environmental protection action plan, i.e. the third (2006–2008) and fourth (2009–2011) three-year environmental protection action plans (Baoshan District Environmental Protection Bureau, 2012). With the main goal of pollution control in the plans, the attention has been paid to the industry sector for reducing pollution in BSD through three measures (i.e. structural, technical and management measures). Two index methods (i.e. RPI and EPI) are introduced to evaluate the situation of air pollution reduction. An investment of about 4.4 billion RMB (USD 677 million in 2000 constant prices) has been made for structural industries, improving the environmental management, and adopting technologies such as the flue gas desulphurization and PM reduction technologies in BSD between 2005 and 2010.

In the period of 2006–2010, BSD has reduced SO_2 emissions by 28,994.6 tons, a reduction of 35.1% compared to the level of SO_2 emissions in the period of 2000–2005. PM emissions were reduced by 1390 tons, which was decreased by 7.7% compared to the level of period of 2000–2005. However, NO_x emissions show an increase of more than 10,000 tons compared to the level in 2000–2005. The main contribution to the increase of NOx was from the transport sector (Baoshan District Environmental Protection Bureau, 2012). Fig. 3 shows the situation of air pollutants changes from 2005 to 2010.

4.1.1. Air pollution control through structural and technical measures

The government of BSD has made great efforts on adopting and updating the measures in pollution control in the industrial enterprises between 2006 and 2009 (Baoshan Development and Reform Commission, 2010). The so-called "structural measure" were designed to reduce air pollution in the local industries by the government through the approach of relocating or closing enterprises with high pollution emission intensity. The term of "technical measures" involve utilizing and upgrading pollution control facilities and technologies such as the technologies of desulfurization, denitrification, and PM elimination.

Table 2
Air pollutants from the industry sector and the transport sector in BSD in 2010.

Air pollutants	Industry sector	Transport sector	Proportion of industrial source (%)
SO_2 (t)	55844.0	83.0	99.9
NO_x (t)	123998.3	4349.0	96.6
Dustfall (t)	16491.8	/	100
PM(t)	16735.3	10554.0	61.3
		Average	**89.5**

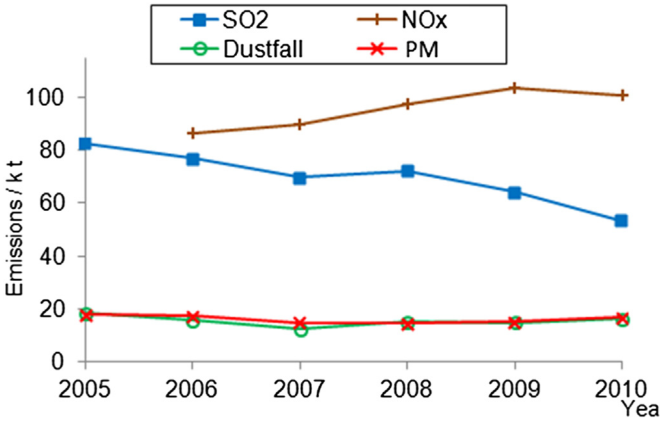


Fig. 3. Changes of air pollutants in BSD between 2005 and 2010.

During the implementation of structural and technical measures, 111 enterprises with high pollution emission intensity were targeted. Among them, 16 enterprises were closed and 60 were moved out of the BSD and relocated in Jiangsu and Zhejiang provinces. In the same period, technologies of reducing pollution have been adopted and updated in 18 enterprises. 84.7% of total targeted enterprises (i.e. 94 enterprises) have been involved in the structural and technical measures. Using SO_2 emission reduction as an example, structural measures resulted in a reduction of 668 tons between 2006 and 2009. In the same period, technical measures of pollution reduction resulted in a reduction of 494 tons (Fig. 4). Fig. 4 shows that the most of technical reduction of SO_2 was made in 2008. In 2006, 2007 and 2009, it is obvious that the structural reduction of SO_2 achieved is higher than the technical reduction in these three years. That is 57.5% of total SO_2 reduction has been made through structural measures, which is higher than 42.5% of total reduction contributed by technical measures within four years. In another word, the structural measures played a more important role in the air pollution control in BSD.

4.1.2. Air pollution control through management measures

Management measures of pollution control (e.g. regulations improving, monitoring and supervision strength, and capacity building) are designed for effectively controlling the pollution.

EPI is used for indicating and comparing the intensity of pollution in 330 enterprises that contribute 95% of total pollution emissions in BSD between 2006 and 2009 (Baoshan District Environmental Protection Bureau, 2011). 30 enterprises (E30) have planned to decrease the total amount of pollution through stricter policies and effective management from 2006. 100 enterprises (E100) have promoted the management in process of updating monitoring and supervision for reducing pollutants, and 200 enterprises (E200) have reduced the total amount of pollution mainly by enhancing internal regulations. After implementing management measures, the pollution situations in 330 enterprises between 2006 and 2009 are evaluated through EPI (Fig. 5). Fig. 5 shows that E30 pollution management index increased from 4800 to 5376 from 2006 to 2007, but decrease significantly from 5376 to 4668 from 2007 to 2009. E100 index declined gradually from 4010 to 3788 between 2006 and 2009. However, E200 index increased slightly from 3930 to 4053 in the period. Fig. 5 also shows that the most of pollution management improvements has been achieved by E30 enterprises.

RPI is another index system adopted for evaluating air pollution situation changes in the industrial area in BSD. A comparison is made to the pollution situation changes in the industrial area of BSD in 2005 and 2009 through RPI (Fig. 6). 150 colored grids which are made based on the geographic location of enterprises are given different colors for representing air pollution situations in BSD. Fig. 6 shows that five black grids (about 17.4 km^2) were eliminated, seven green grids (about 48 km^2) were increased, and the pollution situations of more than 30 grids were improved.

4.2. Energy conservation in the industry sector in BSD

Same measures (i.e. the structural, technical and management measures) for saving energy and carbon emissions have been undertaken between 2006 and 2010. In the period of the Eleventh FYP (2006–2010), the energy consumption intensity was decreased by

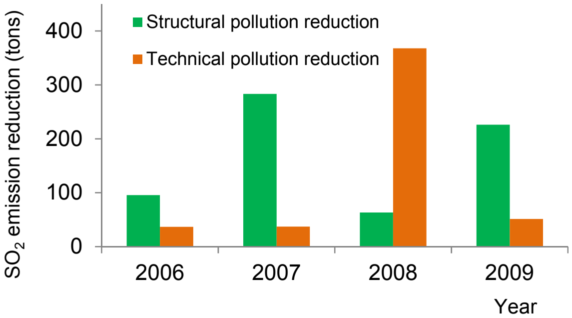


Fig. 4. SO_2 emission reduction achieved through the structural and technical measures in BSD between 2006 and 2009.

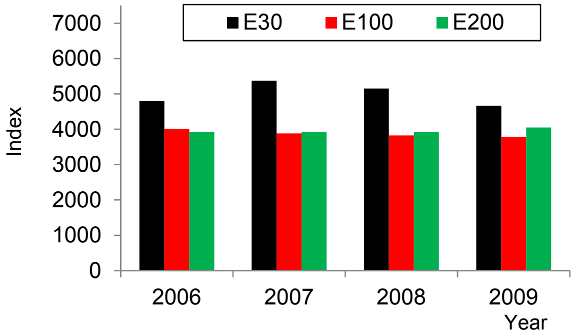
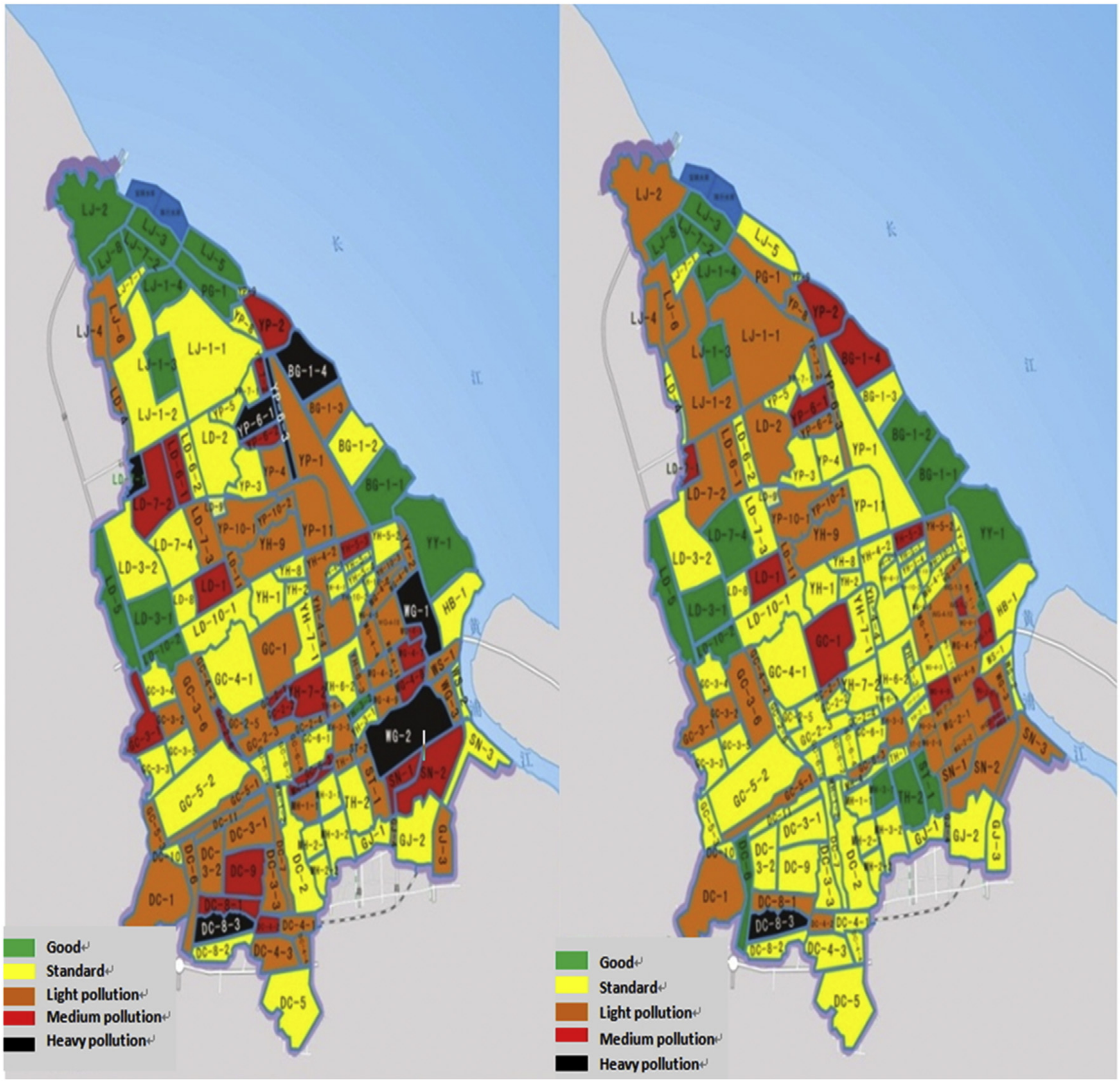


Fig. 5. Pollution situations in 330 enterprises in BSD between 2006 and 2009.



(a)2005

(b) 2009

Fig. 6. Changes of air pollution situation in BSD between 2005 and 2009.

26.7% compared to the level of 2001–2005 in the industry sector in BSD. For instance, the energy consumption by the Above Scale Enterprises[1] was 830,000 tce in 2006, which was reduced by 20.2% (i.e. 210,000 tce) compared to 1,040,000 tce in 2005 (Bsoshan Development and Reform Commission, 2010).

4.2.1. *Energy conservation through structural and technical measures*

200 enterprises with the highest energy use and CO_2 emissions such as electroplating factories and chemical plants were closed and moved out of BSD from 2006 to 2010. 45 industrial manufacturing enterprises with low productive capacity and high energy consumption were upgraded by utilizing advanced energy saving technologies. Structural and technical energy conservation of as much as 110,000 tce was achieved which is equivalent to the emission reduction of 716,320 tons CO_2 in the targeted enterprises between 2006 and 2010 in BSD. For example, a reduction of 4015 tce consumption (i.e. the equivalent of reduction of 26,145 tons of CO_2) was achieved by closing Yuepu thermal power plant in 2009 which was located in the “black grid” area in 2005.

According to the assessment made by the Baoshan Development and Reform Commission (2010), updated and deployed energy saving technologies, closing and relocating projects have substantially achieved the objective of energy conservation and GHG reduction in BSD(Baoshan Development and Reform Commission, 2010). For instance, Over 60 energy-saving technologies were utilized in 45 industrial enterprises with less energy efficiency (including 54 new energy-saving technologies were applied in industrial boilers and energy-saving lighting systems), about 500 tce of energy consumption reduction has been made each year during the period of 2006–2010.

4.2.2. *Energy conservation through management measures*

The energy management has been improved which contains the strength of monitoring and supervision, improving regulations and

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[1] The Above Scale Enterprises are described as the enterprises with an annual revenue of over CNY 5 million in BSD.

capacity building in the industry sector in BSD during the period of 2006–2010. An energy consumption statistical database has been established for the improvement of energy management. All enterprises were required to provide monthly reports of energy consumption and energy saving to the district government, and all data and information from reports were input in the database. 30 enterprises with an annual energy consumption of more than 5000 tce were required to submit detailed reports on energy performance and the energy-saving plans. Meanwhile, all new projects needed to provide the energy conservation and carbon reduction plans at the early design stage. For example, when a new steel plant planned to be built in the industrial park, the investor, Xin Yi (Chen Kai) Co. Ltd, was required to provide the energy saving plan in the design stage with the objective of 7000 tce of energy use reduction.

During the implementation of the measure of improving energy management, CEMI is undertaken for assessing the energy management level in selected 500 enterprises in BSD between 2007 and 2009 (Fig. 7). According to the results of CEMI presented in the figure, the number of black enterprises with the worst level of energy efficiency was decreased by 12.3% and the red enterprises were reduced by 26.9%. In the same period, the green enterprises with the best energy efficiency and yellow enterprises with good energy management were increased by 4.5% and 29.8% respectively. However, the number of orange enterprises was increased by 20.7% in 2009 compared to the number in 2007. It means that the enterprises with the medium level of energy efficiency haven't taken energy management improvement measures within three years. For the situation of energy management in 500 sample enterprises in BSD, the overall energy efficiency has been improved by 10.6% between 2007 and 2009.

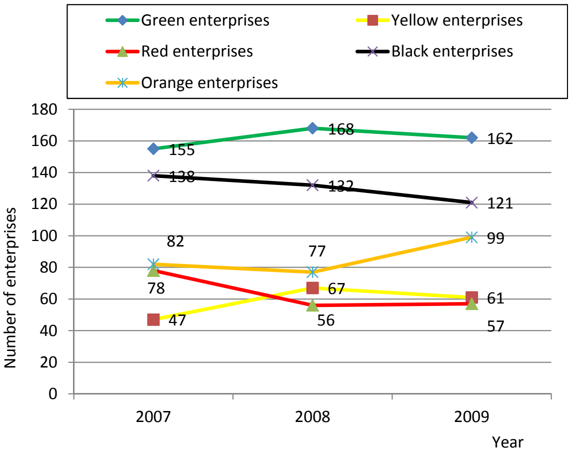

Fig. 7. Energy performance in 500 enterprises between 2007 and 2009.

5. Discussion and recommendations

5.1. Barriers to achieve co-benefits of energy saving and air pollution reduction in BSD

The industry sector plays an important role in the environmental sustainable development in BSD under its long-term development policies. It is clear that policy measures of reducing the coal-dominated energy consumption in Baoshan's industries significantly resulting in co-benefits of cutting GHG and air pollution emissions. Based on the assessment of air pollutants and energy use in hundreds of enterprises made by EPI, RPI and CEMI in BSD from 2005 to 2010, the results show that different scopes and degrees of co-benefits have been delivered by adopting policy measures.

Jiang et al. (2013) pout out that the spatial and temporal differences existing in the air pollution control and energy-related climate mitigation policies, more attention should be put on how to achieve the co-benefits effectively through an integrated approach with addressing various aspects of energy consumption, GHG and air pollutants emissions reduction simultaneously. According to the assessment made to the industry sector in BSD, several barriers need to be addressed in achieving co-benefits effectively:

- More focuses put on the pollution control rather than climate change mitigation at the city level could lead to end up achieving co-benefits effectively. Like other places in China, the local government of BSD has paid more attention on air pollution control because it is more certain and can be reduced easier and quicker locally than the climate change mitigation. Meanwhile, since the Environmental Protection Bureau is responsible for air pollution control and the Reform and Development Commission is responsible for the energy conservation and GHG emissions reduction, most of policies related to the energy use and air pollution control are made and implemented separately without interested consideration. The lack of coordination and collaboration between government bodies and divisions in the process of implementing policies could make the achievement of co-benefits in difficulties.
- It could be not easy to achieve the effectiveness of co-benefits under constrains existing in current measures undertaken in BSD. For instance, structural measures have been both implemented for the energy conservation and air pollution control in BSD. Enterprises with heavy pollution and low energy efficiency have been moved out from BSD. However, the "leakage" emissions of GHG and air pollutants from the places where the displaced enterprises are located now are overlooked. If considering the whole project region (inside and outside of BSD), the achievement of energy saving, air pollutants and GHG emissions could be less because of the ignored leakage missions outside of BSD. Without accounting the overall energy use and air pollution generated within the whole project area, the co-benefits cannot be achieved comprehensively and effectively.
- The results of co-benefits cannot be evaluated validly and effectively under the current index systems. RPI and EPI are adopted for assessing the air pollution control only and CEMI is specially used for evaluated the energy management in different enterprises in BSD. It must be noted that interventions of energy conservation and environmental protection sometimes have contradictory effects. Efforts to achieve overall co-benefits may be weakened if the measures are considered and implemented separately without regard for their interactions. For example, when SO_2 emission is reduced through the desulfurization equipment in the coal-fired power plants, the CO_2 emission is increased by consuming electricity in the process of desulfurization (Li et al., 2012). Therefore, the achieved co-benefits of GHG and air pollution emissions cannot be assessed validly and comprehensively by current index systems.

5.2. Developing an co-benefits indicator system to the industry sector in BSD

It is true that some interventions have natural co-benefits between energy saving and pollution reductions. Worrell and Price (2001) raised an important point that industrial policies are never implemented in isolation; individual policies may have a feedback effect, which can impact the effectiveness of other policies. This is why the concept of co-benefits is emphasized in achieving the environmental sustainability in BSD. Only overcoming the barriers and constrains presented above, an effective co-benefits approach can be established. Solutions such as if policy measures for reducing energy use, carbon emissions and air pollution can be performed synthetically and if highly coordinated policies can be implemented in the industry sector in BSD, there is a high possibility that effective co-benefits of carbon and pollution reduction would be achieved.

Before making the sound policies of environmental sustainability to the industry sector in BSD, the priority is to understand the current situation of GHG and air pollution emissions well. Indicator systems such as RPI, EPI and ECMI have been already utilized for this. However, how to effectively assess the performance of environmental sustainability is still a core question for many scholars even lots of other indicator systems else are developed (Chang and Tsai, 2015). Several main obstacles to the implementation of RPI, EPI and ECMI in BSD are summarized as follows:

- Current indicator systems cannot assess integrated co-benefits of carbon and air pollution reduction in the industry sector in BSD.
- Some data of energy use and pollution emissions only provided by enterprises themselves leads to the results made by RPI, EPI and ECMI not stable and valid.
- Three indicator systems which were designed by government have not been widely and openly applied and tested by no-government organizations (e.g. NGOs). The results worked out by these indicator systems could be questionable and indecent which could lead to possible uncertainties.

Considering these existing constrains and weaknesses in RPI, EPI and ECMI introduced above, a new co-benefits indicator system is proposed by the paper with the aim of evaluating and comparing the effectiveness of co-benefits in the industrial sector in BSD. Based on the local conditions, the co-benefits indicator system could be worked out by combining multiple factors that cover air pollutants, energy performance and GHG emissions under considering the differences between temporal and spatial scales of policies of climate change mitigation and air pollution control. In a general way of establishing the co-benefits indicator system, firstly, all factors related to air pollutants, energy performance and GHG emissions are selected under the effective supervision of government and/or the third party. After making a qualified weight analysis on the selected factors and also having comments and advice from experts to the selected factors, final factors to the co-benefits indicator system can be filtered and confirmed. And then tests can be made for the indicator system in certain industries. Based on the results of tests, the co-benefits indicator system can be finally established and applied in the industry sector in BSD (Fig. 8). Relevant polices can be updated and improved in according with the outcomes of assessment made by using the co-benefits indicator system. This evaluating system can also be replicated and developed in similar industrial districts in Chinese cities to help demonstrating the effectiveness of environmental sustainability achieved through the co-benefits approach.

6. Conclusions

With the significant coal-dominated energy consumption, huge air pollutants and GHG emissions are made by the industry sector in BSD and the environmental problems are becoming more serious, promoting the environmental sustainable development has become the core goal in the sustainable development policies in BSD. Three main policy measures (i.e. the structural, technical and management measures) have been undertaken for reducing pollution emissions and energy consumption in industries in the district. The situations of air pollution control and energy conservation in hundreds of enterprises is assessed by RPI, EPI and ECMI from 2005 to 2010. The results show that the main air pollutants have been reduced and the energy efficiency has also been improved in the industry sector in BSD in the period.

Environmental protection and energy policies carried out in BSD have led to co-benefits between energy saving and pollution reductions. But how to achieve the effectiveness of co-benefits of GHG and air pollution emissions reduction is highlighted in the paper in terms of promoting the environmental sustainable development of BSD.

Analysis made in the paper shows that the co-benefits of pollution reduction and energy conservation have been achieved at

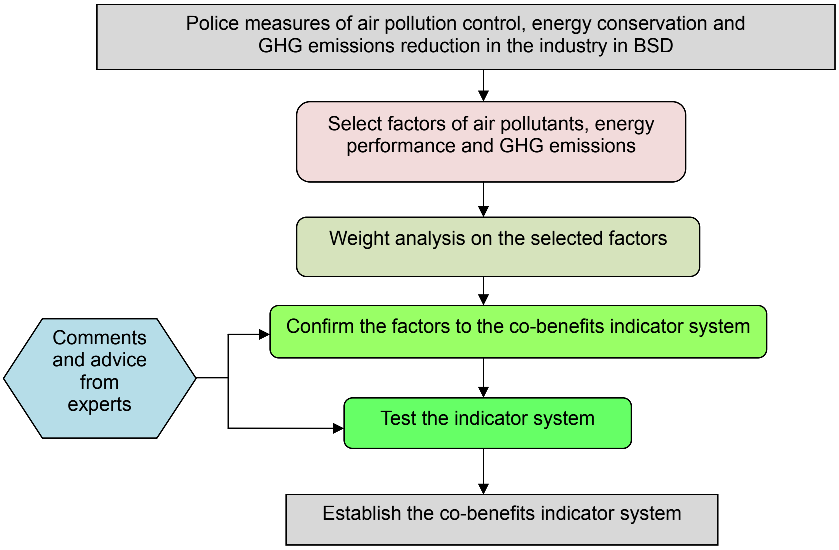

Fig. 8. The framework of forming the co-benefits indicator system.

certain scopes and degrees in the industry in BSD, but not effectively due to the barriers existed in current policy measures. The lack of co-planning and co-operations in the process of designing and implementing the policies and the overlooking the leakage of emissions in the whole project area are main barriers. Meanwhile, the overall co-benefits cannot be assessed validly and comprehensively through RPI, EPI and ECMI because the existing weaknesses and constrains in current index systems. A co-benefits indicator system is proposed by the paper for evaluating the overall co-benefits effectively. More importantly, current policies could be improved and more new sound policies could also be formed based on the results of analysis worked out by the co-benefits indicator system.

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