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Research article

A study on atmospheric environmental resource accounting: A case of SO_2 capacity resources in Chinese provinces

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ABSTRACT

Ecological civilization construction in China is in its critical period and the natural resources assets are audited to the administration. However, the natural resources accounting is still in its infancy, especially the atmospheric environmental resources accounting, which refers to the ability of the atmospheric environment to accommodate and purify certain pollutants. This paper established a methodology to calculate the atmospheric resources assets with the index of SO_2, a convenient method to calculate the physical accounts for atmospheric environmental resources based on the capacity of SO_2 and an accessible way to estimate the monetary accounts with market-based price. Based on the methodology, a calculation was conducted on the assets and liabilities of SO_2 capacity resources for 31 provinces of China in 2015. Empirical results showed that the physical accounts for SO_2 capacity resources quantify the environmental pollution status in each region, and the monetary accounts reflect whether the industry and energy structures in one region are sound and sustainable. The findings provide specific profit or loss in terms of physical and monetary accounts for each region, which enable to quantify the government's occupancy and affordability of SO_2 capacity resources, and contribute to the establishment of natural resource balance sheet and ecological compensation mechanism.

1. Introduction

In November 2013, the Third Plenary Session of the 18th Central Committee of Communist Party of China (CPC) approved “Decision on Major Issues Concerning Comprehensively Deepening Reforms”, which proposed for the first time to “explore ways to compile a natural resources balance sheet and implement natural resources audit when leading officials leave their positions. A lifelong accountability system for ecological and environmental damage shall be established” (CCCPC, 2013). Since then, Chinese government departments and scholars have been actively exploring the preparation of natural resource balance sheets. The National Bureau of Statistics, the Ministry of Land and Resources, the Ministry of Environmental Protection, the Ministry of Forestry and the Ministry of Water Resources have made some efforts to its implementation. Some regional natural resources balance sheets have been reported in Huzhou City, Shenzhen City, Chengde City and Meizhou City. About 295 papers related to it were published in China National Knowledge Infrastructure (CNKI) Database from 2014 to 2017 (Du et al., 2018). How to compile natural resource balance sheets raises a serial of controversial issues, and the natural resource accounting is the core and foremost for it.

The natural resource accounting was done in the 1970s and drew the world attention in the 1980s (Lange, 2007). In the 1990s, the United Nations proposed the System of Integrated Environmental and Economic Accounting (SEEA) as a satellite system to the System of National Accounts (SNA). The SEEA has evolved three editions from 1993, 2003 to 2012, and become an international statistical standard that describes stocks and changes in stocks of nature resources assets (UN et al., 2014). More and more countries have experienced natural resource accounting, and researchers and policy makers have studied different kinds of measurements in both physical and monetary accounts for various resource types, such as land (Robinson et al., 2017), water (La Notte and Dalmazzone, 2018), forest (Gundimeda et al., 2007; Mazziotta et al., 2016), energy (Hossaini and Hewage, 2013), and minerals (Zhang et al., 2018). Atmosphere is always related to gas emissions and regarded as environmental protection expenditure, but

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rarely included as a kind of natural resources.

The atmosphere is crucial for the survival of the biosphere and human well-being; however, its immense social and economic value to society is largely ignored and taken for granted (Walker, 2007). The atmosphere controls local weather, global climate systems, dispersal of pollen and seeds, dissipation of waste gases, and the quality of air we breathe, therefore, it is necessary to communicate the economic value of atmospheric resources and services to everyone, from governments to general public. Thornes et al. (2010) identified 12 atmospheric services representing the main uses of atmospheric resource to support human life on earth, while the total economic value of the atmosphere was roughly estimated in a range, i.e., each atmospheric service was shown a ranking value and the figures were initially exploratory estimates. Kendall et al. (2014) tried to quantify most of the 12 atmospheric services using Geographical Information Systems (GIS), but did not study the economic value of these services. Recently some scholars (Guo et al., 2018; Li et al., 2019) paid attention to the atmospheric environmental carrying capacity, but they only focused on the evaluation of the resources by index, and did not provide specific numerical calculation.

The atmospheric resources are powerful and diversified: some seem impossible to quantify, such as aesthetic, spiritual and sensual properties of the atmosphere; some are already included in the ecosystem services of water, forest, soil and energy nature resources such as redistribution of water services, direct use of the atmosphere for ecosystems and agriculture, atmospheric recreation and climate tourism, and direct use of the atmosphere for power; the others may need complicated methodology or may not have sufficient data to quantify and valuate. However, the most important value of atmospheric resources tangible to the public and closely related to economic activity may be the cleaning capacity of the atmosphere, which is associated with environment pollution and air quality.

This paper focuses on the cleaning capacity of the atmospheric environmental resources. When human discharge various pollutants into the atmosphere, they are actually using the service of atmospheric environmental resources. Atmospheric environmental resources refer to the ability of the atmospheric resources to accommodate and purify pollutants. An air quality index (AQI) is used by government agencies to communicate to the public how the air quality is, and therefore reflecting atmospheric environmental resources. Different countries have their own AQIs, corresponding to different national air quality standards. Some basic indicators covered in every country's AQI include sulfur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3), and suspended particulates. Among them, sulfur dioxide is a major air pollutant and has significant impact upon human health. It's possible to quantify the atmospheric environmental resources by calculating the capacity of the atmosphere accommodating the indicators, especially sulfur dioxide in a region.

In China, the emissions of air pollutants such as SO_2 are controlled based on the existing emission levels, confining the emissions to or less to their historical emissions. It does not reflect the value of those regions with few or no pollutants in the past, especially those regions characterized with the development of ecology and tourism as pillar industries. Therefore, it is necessary to quantify and valuate the atmospheric environmental resources, reveal the government's occupancy and affordability of natural resources, and prevent the local governments from sacrificing environment in exchange for economic growth.

This paper intended to establish a simple and valid approach to measure the physical and monetary accounts for atmospheric environmental resources with the index of SO_2. Quantitative and valuating methods of atmospheric environmental resources are elaborated in Section 2. The 2015 SO_2 capacity resources accounting in 31 provinces of China are presented in Section 3. Research conclusions are drawn in Section 4.

2. Methods and data sources

2.1. Physical accounts for atmospheric environmental resources

Sulfur dioxide (SO_2) emission is one of the most serious air pollution problems in China, causing a series of environmental and health issues. Sulfur dioxide emission is a precursor to acid rain and atmospheric particulates. Of 463 cities of China where the rainfall is monitored and recorded, 36.1% suffers acid rain (MEE, 2018). The concentration of sulfur dioxide in the atmosphere can influence the habitat suitability for plant and animal life. Sulfur dioxide can affect the respiratory system and the functions of lungs, and cause irritation of eyes. Hospital admissions for cardiac diseases and mortality increase significantly on days with higher SO_2 concentration levels. Therefore sulfur dioxide is chosen as an index to study the atmospheric environmental resources accounting, i.e. quantification of the cleaning capacity of SO_2.

The assets accounts for atmospheric environmental resources in this paper mainly include the opening and closing stocks of capacity of SO_2, and the changes in the stocks over an accounting period. The physical changes in the stocks are the annual SO_2 emitted in a certain area if one year is set as an accounting period. This data has already been recorded in details by the environmental protection departments. Atmospheric environmental capacity (AEC), i.e., how much the pollutants are allowed to be discharged in the atmosphere, is used to determine the physical opening stock of capacity of SO_2 in a certain area. Given the environmental objective (air quality standard) as a constraint, an environmental quality model can be used to calculate the AEC.

There are usually three categories of models for measuring AEC. The first is the linear programming method (An et al., 2007) mainly suitable for small spatial scale and can't deal with non-linear air pollution problem. The second is the simulation method, such as the Industrial Source Complex (ISC) Dispersion Model developed by US Environmental Protection Agency (USEPA, 1995), the AERMOD developed by a collaborative working group of scientists from the AMS (American Meteorological Society), the US EPA (USEPA, 2004) CALPUFF modeling system developed by scientists at Exponent, Inc (Exponent Inc., 2018), Atmospheric Dispersion Modeling System (ADMS) developed by Cambridge Environmental Research Consultants from UK Cambridge University (CERC, 2017), and so on. Demirarslan and Doğruparmak (2016) evaluated the performance of different simulation methods, and found that data used in these models are quite complicated and difficult to obtain for their country. In fact, the basic information in these models is usually established with emission source scenarios, which only considers pollutant emissions while ignores pollutant removal-accumulation processes. Moreover, this approach usually requires many assumptions, which produces a negative effect on its reliability and applicability.

The third is A-value method, which is mainly dependent on natural conditions and independent of the properties of emission sources, and the data examined represents a relatively homogeneous population with relatively stable statistical aspects. The A-value method is widely applied in controlling air pollution in China. The Chinese State Bureau of Technical Supervision (CSBTS) and the National Environment Protection Agency jointly issued the national standard “Technical Methods for Emission Standards for Air Pollutants (GB/T 3840-91) "(CSBTS, 1991), in which A-value method for the total emission limits of a control area was proposed. The A-value method is a national standard method and requires fewer conditions and has been recognized in determining regional atmospheric environmental capacity in China (MEP, 2003). In contrast, other methods and models require a large quantity of data such as emission source data and meteorological data, a large amount of computer processing and given scenarios. Therefore, A-Value method was adopted in this paper.

A-value method is based on the box model, where the control area is regarded as a box. The bottom and the top of the box are respectively the underlying surface and the top of the atmosphere mixed layer, and the circumference is determined by the range of the area. The total capacity formula for SO_2 emissions in the control area can be expressed as:

$$Q_a = AC_S\sqrt{S} + 3.1536C_sS(u_d + W_r R + H_i/T_c) \tag{1}$$

where

Q_a is the total capacity of SO_2, i.e. the annual total allowed SO_2 emission limit in the control area (10^4t/a);
C_s is the standard limit of annual average pollutant (SO_2) concentration (mg/m^3);
S is the total control area (km^2);
u_d is the dry deposition rate (m/s);
W_r is the cleaning ratio;
R is the annual average precipitation rate (mm/a);
H_i is the height that the pollutant (SO_2) can reach, generally the mixed layer thickness (m) under different meteorological conditions; and
T_c is SO_2 conversion time constant or half decay cycle.

The front part of the formula is the advection and diffusion of atmospheric pollutant (SO_2), and the back part includes the dry deposition migration, wet deposition migration, and chemical conversion.

When only the total emission control of gas pollutants is considered in the general urban area, the dry and wet deposition migration items can be neglected since the wet deposition migration effect is far less than the dilution effect of ventilation, due to general annual rainfall (CSEPA, 1991). The chemical conversion item can also be ignored as the half-life of the pollutant is long enough. Therefore, the above formula can be simplified as follows:

$$Q_a = AC_s\sqrt{S} \tag{2}$$

The allowed pollutant total emissions in the control area (total capacity) are only associated with the area, the ambient air quality control objectives, and the local A-value. It can be seen from $A = 3.1536 \times 10^{-3}\sqrt{\pi}\ V_E/2$ that the A-value is a constant related to the local average ventilation (V_E). If the local average ventilation cannot be obtained, a default A-value in various regions of China can be obtained from the "Technical Methods for Emission Standards for Air Pollutants GB/T 3840-91".

According to the above method, the total capacity of SO_2 in a certain period and region, i.e., the opening stocks of capacity of SO_2, can be calculated. The actual emissions of SO_2 in the same period and region, i.e., the changes in the stocks, have been long-term compliantly monitored and recorded. Then, the stocks at the end of the period (i.e., the closing stocks) can be calculated by subtracting the opening stocks from the changes in the stocks when the opening stocks and the changes in the stocks are determined.

In China, the provincial region is the most important administrative unit in policy formulating, and the central government allocates the pollutant emission control targets to each province. In the present study, the asset accounts for atmospheric environmental resources with the index of SO_2 cover all 31 provincial administrative regions of China, i.e. four municipalities (Beijing, Tianjin, Shanghai and Chongqing), five autonomous regions (Inner Mongolia, Ningxia, Guangxi, Xinjiang and Tibet), and 22 provinces, excluding Hong Kong, Macau and Taiwan. For each province i, the closing stocks of capacity of SO_2 in 2015 are expressed as following:

$$X_i = [A_i^{min} + (A_i^{max} - A_i^{min}) \times (1 - P)] \times C_S \times \sqrt{S_i} - ES_i \tag{3}$$

where:

A^{min} and A^{mas} are respectively the minimum and maximum A-values for province i according to "Technical Methods for Emission Standards for Air Pollutants GB/T 3840-91";
P is the standard guarantee rate (it is set to 90% based on the National key cities atmospheric environment capacity verification work program (MEP, 2003));
C_s is the annual average concentration limit of SO_2 (according to the national air quality standard (MEP, 2012). Specifically, the first-level concentration limit is 0.02 mg/m^3 and the second-level concentration limit is 0.06 mg/m^3);
S is the national land area (km^2) in province i, based on the statistics from local government websites; and
ES is the emission of SO_2 released by province i in 2015(10,000 tons), which is from China Statistical Yearbook in 2016 (NBSC, 2016).

If the emissions of SO_2 are lower than the total capacity, it means that there is surplus in the atmospheric environment resources in the region; if the emissions of SO_2 are higher than the total capacity, it means that the atmospheric environment resources in the region are indebted.

2.2. Monetary accounts for atmospheric environmental resources

How to valuate the natural resources is the key for monetary accounts. Various methods for their valuation have been tested and applied, and can be classified into two types based on their theories from different perspectives. One is environmental type such as emergy (Odum, 1996) and exergy (Dewulf et al., 2008), which emphasizes natural consumption and environmental impacts from physical perspectives. However, this type has uncertainty in data source and transformity, and the results are difficult to understand and utilize (Dong et al., 2016).

The other is economic type including Cost Benefit Analysis (CBA) (Bachmann and van der Kamp, 2014) and market value method (Woodward and Wui, 2001), which can monetize the natural resources. The CBA method can quantify the losses on human health and the cost of environmental damage. But it is difficult to define all the losses and cost, and has the limitation to quantify some environmental, ecosystem and social benefit (Söderqvist et al., 2015). The market value method can give a specific price to a kind of natural resource based on the market's "invisible hand" which plays an increasingly important role in the effective allocation of resources. In the SEEA, as in the SNA, the values reflected in the accounts are, in principle, the current transaction values or market prices for the associated goods, services, labor or assets that are exchanged. From the perspective of linking environmental resource value calculation with SNA, we believe that the preferred choice of evaluating environmental resources is to seek a valuation method based on the market price; Moreover, it is easier to understand and acceptable by public and governments.

As the main market-based instruments, both environmental taxes and tradable permits can create a price signal as incentives for emissions reductions and leave firms the flexibility to pursue whatever abatement strategy is least costly for them (Stavins, 2003). The United States (US) issued both of them as early as 1970s. Environmental taxes are developed on the theoretical basis of Pigovian tax, a tax on any market activity that generates negative externalities. In 1972, the US took the lead in the introduction of sulfur dioxide tax, which directly levied on the pollution activity itself, the amount of SO_2 emission. In the area where concentration meets the primary and secondary standards, 15 cents and 10 cents were levied for each pound of emission respectively to induce producers to install pollution control facilities and switch to low sulfur fuels (Ura and de Pablos, 2012). The tax rates are transformed as 330.7 USD/ton SO_2 in primary standard and 220.5 USD/ton SO_2 in secondary standard for the data comparison below.

The theoretical basis of the emissions trading system is Coase Theorem, which describes the economic efficiency of an economic allocation or outcome in the presence of externalities. After the 1977 Clean Air Act Amendments recognized the offset policy ("bubble" policy) for emissions in law, Title IV of the 1990 Clean Air Act Amendments (CAAA) initiated the first large scale use of the tradable permit approach to pollution control, also known as the Acid Rain Program and the SO_2 allowance-trading system. It is widely viewed as a success, and by far the most extensive SO_2 emission trading system which has reliable legal basis and detailed implementation plans and covers all power industries in the US.

There are two different venues in which allowance trading takes place. The first venue is called primary market, where allowances are traded through a set of annual auctions that Section 416(d) (2) of the CAAA requires the Environmental Protection Agency (EPA) to hold. The auctions were first held in March 1993, and took place every March since then. Based on the EPA Allowance Auction Results (USEPA, 2018), the clearing prices of SO_2 allowances in spot auction from 1993 to 2018 are shown in Fig. 2. The prices were relatively stable at the average price of 139 USD/ton in the first decade; after 2004, it then fluctuated greatly from the highest 860 USD/ton to the lowest 0.04 USD/ton, which did not truly reflect the normal SO_2 emission reduction cost, but mainly due to policy changes and regulatory errors. Hitaj and Stocking (2016) found evidence that the prices in the SO_2 market can reflect marginal abatement costs before the court decision that introduced significant uncertainty into the market.

Once the allowances were distributed or auctioned, they could be traded in a secondary market, which involved bilateral private trades between utilities that owned electric generators or between utilities and third parties. The price in secondary market tends to be proprietary and difficult to obtain, and can only be referred from some organizations or associations. Joskow et al. (1998) found that the clearing prices yielded by the March 1994, 1995, 1996, and 1997 auctions were virtually identical to the transaction prices reported by Cantor Fitzgerald, the Emission Exchange Corporation, and Fieldston (EATX). The price trendy in primary market from Fig. 1 is very similar with the monthly SO_2 price index in secondary market where Hitaj and Stocking (2016) purchased from Cambridge Energy Research Associates. According to Hitaj and Stocking (2016), the SO_2 allowance prices had an average of 147 USD/ton for the previous 10 years, then soared to more than 1600 USD/ton, and then fell to almost zero in response to changes to the program and related legal decisions.

The two market-based instruments co-exist in China recently. The Environmental Protection Tax Law of the People's Republic of China (EPT Law) came into force on January 1, 2018 (NPC, 2016), replacing the existing Pollutant Discharge Fees (PDF) system to strengthen the enforcement of environmental regulations. Within 30 years of implementation, the PDF system was improved constantly to reflect actual discharge levels and economic consequences of pollution activities more precisely. According to the existing and latest PDF system (NDRC, 2014), the charge for SO_2 emission is not less than 1.2 CNY per stipulated quantities (pollution equivalent), and the pollution equivalents is calculated by dividing the SO_2 emission by the pollution equivalent values of 0.95 kg. That is, the charge fee is 1263 CNY (203 USD[1]) per ton SO_2 emission. The calculation mechanism in the EPT Law is basically consistent with the PDF system. The EPT Law provides a minimum tax rate of 203 USD per ton SO_2 emission. The law grants provincial governments discretion to adjust the applicable tax rate up to ten times the national standard level.

In 2000, the Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution stipulated that the ownership of atmospheric resources belongs to the nation (NPC, 2018), which provided the legal and institutional foundation for the widespread implementation of emission trading. At present, some regions have conducted their own emission trading experiment by establishing trading rules and online/offline trading platforms.

The price in primary market (also called acquisition fees in China), which was determined by each region, varied greatly from 32 to 257 USD/ton among regions[2] (GDDRC et al., 2016; FJPB, 2018; HNDRC et al., 2016; ZJPB et al., 2016; IMDRC et al., 2016; SXDEP et al., 2016), because there were big differences in terms of the scarceness of local environmental resources, the levels of local economic development, and the costs for abating local pollution. As the pilot trading markets were generally thin, congested, and unsafe, the transaction prices in most of regions (HXEE, 2018; HNETC, 2018; ZJETN, 2016; IMEED, 2018; SXERE, 2018) were more variable from 32 to 11356 USD/ton both between and within regions, except for Guangdong Province (GDEE, 2018). Only the price in a stable and effective market can be used to valuate the environmental resources, therefore only the prices in Guangdong province are shown in Table 1.

It shows in Table 1 that the price of SO_2 emission ranges from one to three hundred USD per ton. Given China's regional diversity in economic, social, and resource endowments, it is necessary to valuate the environmental resources based on local acquisition fees. However, since the "paying for acquisition" requirement is just in the pilot phase and might exert a powerful influence on current polluters, most pilot regions are still discussing their local acquisition price structure, let alone other regions. So the baseline SO_2 tax of 1263 CNY/ton (203 USD/ton) is used as an average price to valuate the SO_2 capacity in each province of China. Moreover, the price is the same order of magnitude as the US SO_2 tax and allowance prices for the last 10 years, and such price is close to the price in Guangdong Province where the SO_2 prices in primary and secondary market are close and stable.

With market price method, asset value of the capacity of SO_2 at the end of period (V_t) is calculated as the (X_t) multiplied by the market price (P_t).

For each province i, the closing value stocks of the capacity of SO_2 in 2015 are expressed as following:

$$V_i = X_{i*}P_i \tag{4}$$

Where:

X_i is physical volume of the closing stocks in 2015(ton); and
P_i is the market price in province i, and a national average market price of 203 USD/ton is used in this paper.

3. Results and discussion

3.1. Physical accounts for SO_2 capacity resources in each province of China

According to formula (3), physical accounts for SO_2 capacity resources in each province of China in 2015 can be calculated when the C_s is set at the first- and second-level in the national air quality standards respectively. In addition, according to the National Bureau of Statistics of China (NBSC, 2011), the 31 provincial regions can be conventionally divided into four areas, i.e., the Northeastern, Eastern, Central and Western areas, based on the socio-economic development status, as shown in Fig. 2.

The larger the area of a province is, the more the opening stocks of the province are, as the latter is proportional to the former. Under the national first-level air quality standard (Fig. 3), the total opening stocks of the capacity of SO_2 in China amount to 1385.56 (10^4t SO_2), which is close to the other research results (Xue etc, 2014) where the national carrying capacity of SO_2 is 1363.26 (10^4t SO_2) with the constraint of annual average ambient PM2.5 concentration standard based on an iterative algorithm combined with a simulation model. The western

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[1] Based on the National Data from National Bureau of Statistics of China (NBSC), the average exchange rate between RMB and USD (USD = 100) in 2015 is 622.84(yuan), which is adopted in the paper.

[2] The price information in other regions may be not available in the internet or does not exist because the programs is still under discussion or there is no transaction so far.

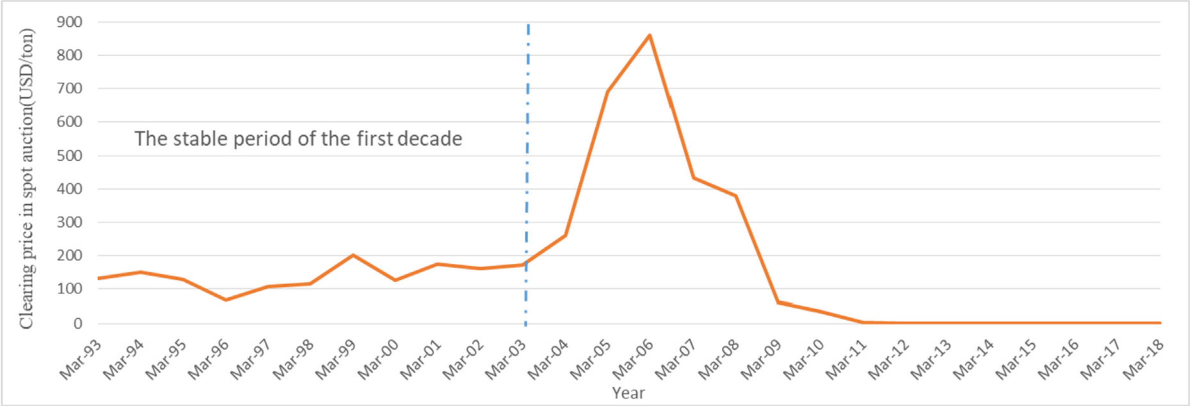

Fig. 1. The clearing price of SO_2 allowances in spot auction from 1993 to 2018.

Fig. 2. Regional distribution of Mainland China.

Table 1
The price of SO_2 emission from market-based instruments.

Countries	Categories		Price
United States	SO_2 tax (since 1972)	Primary standard area(high SO_2 concentration)	331 USD/ton
		Secondary standard area	221 USD/ton
	Emission trading system	Primary market(average auction price from 1993 to 2003)	139 USD/ton
		Secondary market(average transaction price from 1993 to 2003)	147 USD/ton
China	SO_2 tax	EPT Law (taking effect in Jan. 1st, 2018)	203 USD/ton (baseline price)
		Pollution discharge fee (expired in Jan. 1st, 2018)	203 USD/ton
	Emission trading system (Guangdong Province)	Primary market (acquisition fee since 2013)	257 USD/ton (GDDRC et al., 2016)
		Secondary market (average transaction since 2013)	276 USD/ton (GDEE, 2018)

region with the largest area contributed the largest share of 58.5%, followed by the eastern region (15.6%), the central region (13.4%) and the northeastern region (12.5%). By subtracting the opening stocks from the changes in the stocks, the national total closing stock of the capacity of SO_2 was $-473.56(10^4t\ SO_2)$ in 2015, meaning that the SO_2 environment resources of China in 2015 were indebted. The northeastern, eastern, central and western region was respectively responsible for 1.3%, 70.1%, 54.0% and −25.44% of the national total closing stocks, where only the closing stocks of western region was surplus. The closing stocks of capacity of SO_2 in different regions are negatively correlated with the level of socio-economic development, that is, the higher the level of socio-economic development is, the fewer the closing stocks of capacity of SO_2 is.

At the provincial level, only seven provinces' SO_2 emissions were below the opening stocks of the capacity of SO_2. The top 3 provinces with the largest opening and closing stocks are Tibet, Xinjiang, and Qinghai provinces, which are all from western regions and have a vast territory with a sparse population. The other three provinces (Heilongjiang, Jilin, and Hainan) are dominated by relatively larger forest lands and fewer SO_2 emission companies. The last one is Beijing,

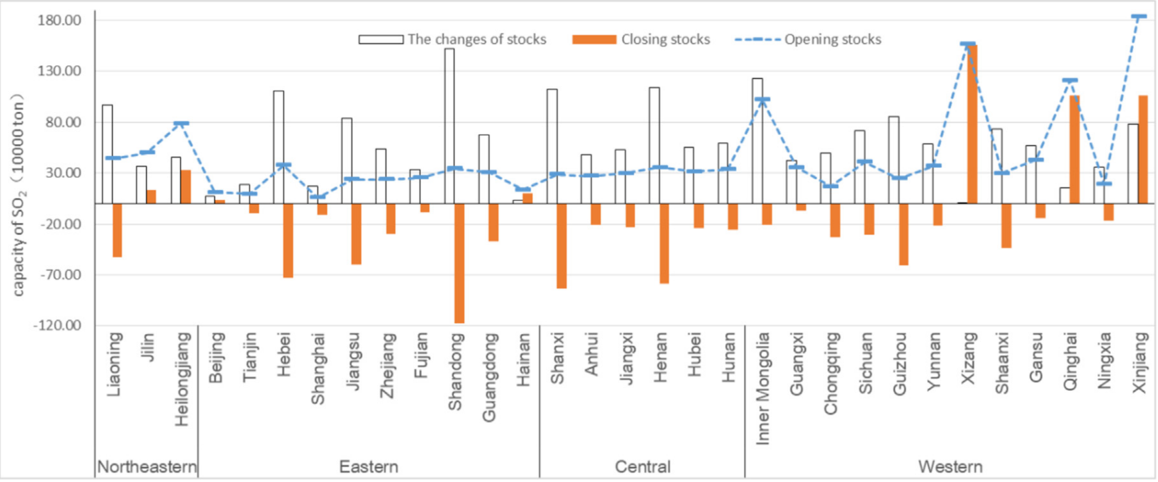

Fig. 3. Physical accounts for SO_2 environment resources in each province of China in 2015(first-level concentration limit of 0.02 mg/m^3).

the capital of China, where pollutant emissions are strictly controlled and most of heavy industries have been removed to its neighbors such as Hebei province. The provinces with the closing stocks in debt up to 70 (10^4t SO_2) are Shandong, Shanxi, Henan and Hebei, where concentrate a lot of heavy and pollutant industries.

If the C_s is degraded to the second level standard (Fig. 4), i.e., the opening stocks of the capacity of SO_2 are tripled. The national total closing stock of the capacity of SO_2 was surplus with the amount of 2297.56(10^4t SO_2) in 2015. In this case, all provinces had enough space for SO_2 emissions, except for five provinces including Shandong, Shanxi, Jiangsu, Guizhou, and Henan. Of them, Shandong province was in the highest debt, with the closing stocks nearly to 50 (10^4t SO_2), which was almost the sum of the other four provinces.

3.2. Monetary accounts for SO_2 capacity resources in each province of China

Combined with the physical accounts for SO_2 capacity resources, the monetary accounts can be calculated using formula (4).

It shows from Fig. 5 that the distribution characteristics of monetary accounts in each province are the same as the physical accounts because the difference between them is a multiple of market price. With the first-level air quality concentration limit, the total profit and the value loss of the closing stocks in all provinces are relatively balanced and basically at the same order of magnitude. The closing value of stocks in Tibet, Xinjiang, and Qinghai provinces with more surpluses are from 200 to 300 million USD. The closing values of stocks in the provinces with large debts are around 200 million USD, and those in other provinces fluctuate within 100 million USD. Within the limitation of the second-level, the closing values of stocks in most provinces are surplus and vary greatly. The values of the closing stocks in Tibet and Xinjiang with more surpluses are as high as 900 million USD, while the majority of provinces' profit and loss fluctuates within 100 million USD. One important function of the natural resources balance sheet is to provide theoretical and technical support for the establishment of ecological compensation standards and mechanisms. If the gap among the closing value of stocks in each region is too large, it is not beneficial for the determination of ecological compensation standards. Moreover, the national first-level air quality standard is more in line with the current goal of Chinese people "pursuing a happier and healthier life". Therefore, the calculation of the opening stocks of atmospheric environmental resource assets should give priority to the use of the national first-level air quality standard for pollutant concentration limits.

Economic development level and industry and energy structures influence the patterns of the closing values of stocks. The closing value of SO_2 capacity resources and GDP in each province of China in 2015 are compared in Fig. 6. The total closing values of stocks under first-level air quality standard is -0.96 billion USD in debt, which is tiny (0.008%) relative to the gross domestic product (GDP) of 11604 billion USD in 2015. But six provinces' ratios between the closing value of SO2 capacity resources and GDP are more than 0.05%. A half of the six provinces are surplus in the closing values of SO_2 capacity resources,

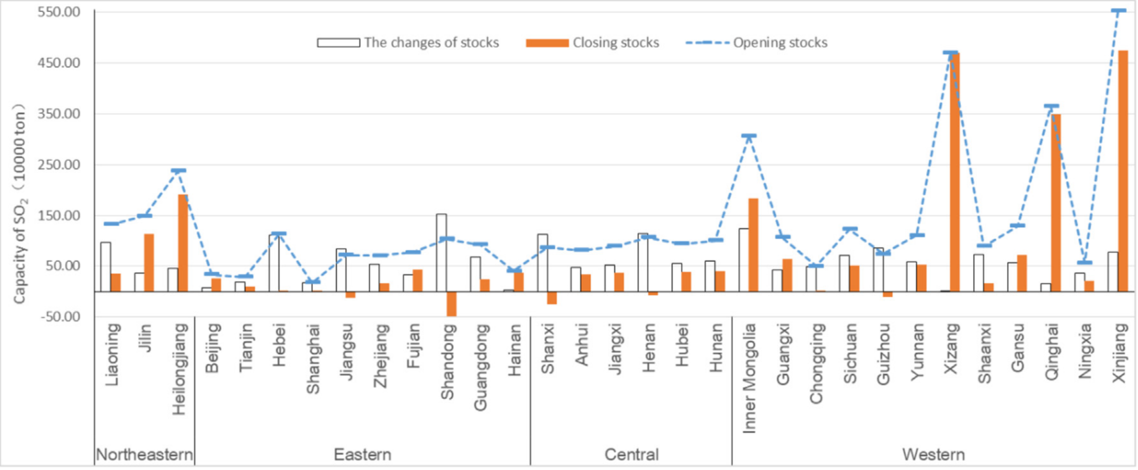

Fig. 4. Physical accounts for SO_2 environment resources in each province of China in 2015(second-level concentration limit of 0.06 mg/m^3).

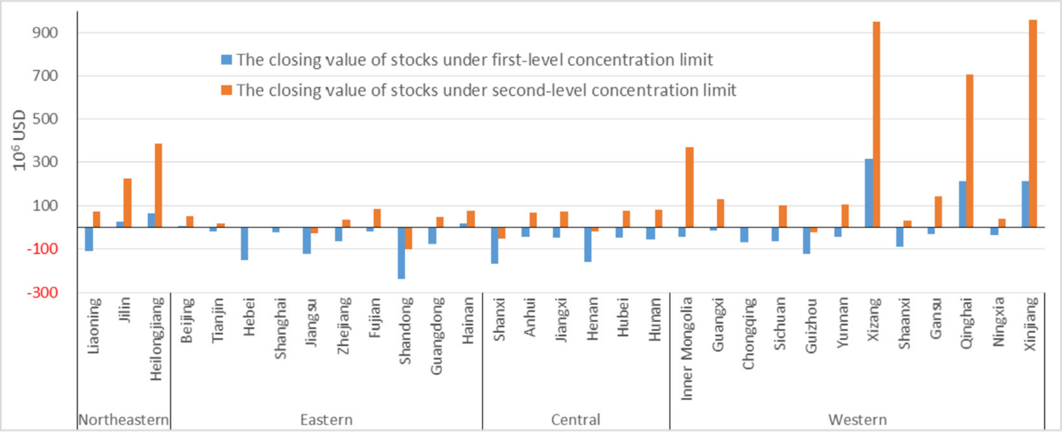

Fig. 5. Monetary accounts for SO_2 capacity resources in each province of China in 2015.

and the other half are in debt. The ratios in the three surplus provinces are over 0.1%, and the Tibet province has the highest of 1.92%.

The relationship between regional per capita GDP and the closing values of stocks of capacity of SO_2 under national first-level air quality standard is shown in Fig. 7. Based on the national average per capita GDP and the balance point of closing stocks of capacity of SO_2, four areas can be differentiated: upper right, bottom right, upper left and bottom left. Only one region, Beijing, lies in upper right area which owns both better economy and higher closing stocks. The upper left area, possessing higher closing stocks but worse economy, includes six provinces: Xizang, Xinjiang, Qinghai, Heilongjiang, Hainan and Jilin, most of which locate in remote areas. Nearly one third of provinces lie in the bottom right area which have better economy but lower closing stocks, and they are all rich provinces in eastern region or close to eastern region, including the top 4 in GDP (i.e. Guangdong, Jiangsu, Shandong and Zhejiang). The bottom left area, representing both worse economy and lower closing stocks, covers all the central region provinces and the western provinces next to the central region, and accounts for nearly a half of all provinces. As it lies in the most bottom left area, Guizhou province represents the lowest economy and closing stocks, and such result is consistent with those reported previously. Liu and Wang (2017) found that Guizhou had the highest pollution terms of trade (PTT) value of 6.646 (PTT = 1 is the threshold above (below) which the province becomes an environmental loser (winner) under trade balances). There is serious concern that the developed eastern regions tend to upgrade industries and may consequently transfer pollution to less developed regions such as the provinces in the bottom left area. The economy in these poor provinces has not yet developed, but the environment has already deteriorated. In undertaking industrial transfer, the policy makers in these provinces should provide tax incentives to pollution control technology and strengthen environmental regulations, so as to realize the win-win development in economy and ecology.

The unbalanced development in upper left area and bottom right area reflects that the economical level can't match with the environmental status in China. It may be still at the stage of the pre-turning point in the Environmental Kuznets Curve (EKC), which is a hypothesized relationship between environmental quality and economic development in an inverted U-shaped curve. The EKC suggests that the solution to pollution is economic growth, and the inverted-U relation is only evident in some cases, not all cases (Arrow et al., 1995). The solution to environmental degradation lies in institutional reforms. Ecological compensation among regions may be a good solution. Based on the monetary accounts for SO_2 capacity resources in each province, the rich provinces in bottom right area can purchase the environmental resources from the poor provinces in upper left area for realizing the interest-balance of different economic subjects.

4. Conclusion

The atmospheric environment represents a major issue related to human health and livelihoods, but it has always been presented much more as an adverse and costly consequence rather than as a resource. In this paper a simple and valid approach were established to valuate the cleaning capacity of the atmospheric environmental resources with a representative index of SO_2. It's feasible and reasonable that the physical accounts for SO_2 environment resources in each province of China were calculated by using A-value model and monetary accounts were

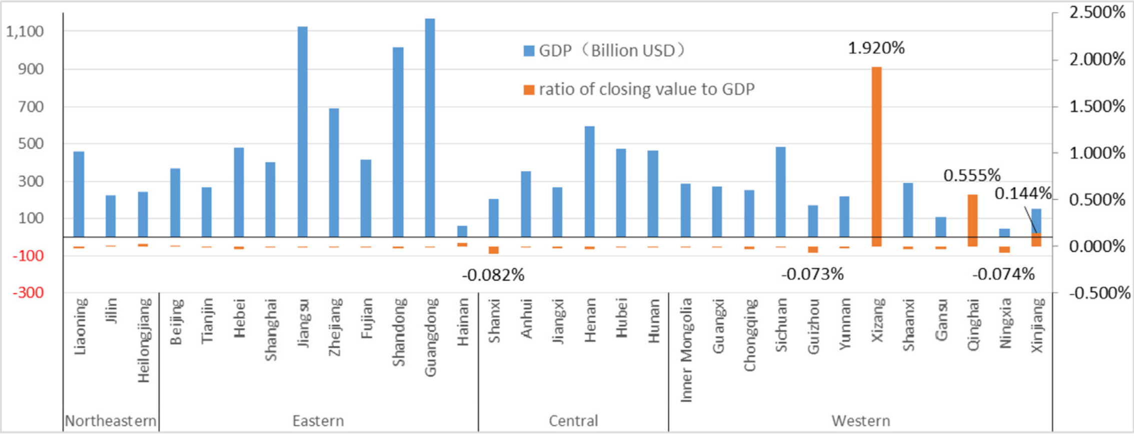

Fig. 6. The ratio between the closing value of SO_2 capacity resources and GDP in each province of China in 2015.

Note: The size of the sphere represents regional GDP

Fig. 7. The relationship between regional per capita GDP and closing values of stocks of capacity of SO2 in each province of China. Note: The size of the sphere represents regional GDP.

monetized by the alternative prices from SO_2 tax and emission trading market.

The national total closing stocks of the capacity of SO_2 was surplus with the limitation of second-level air quality standard, but indebted with the first-level standard. The latter limitation is preferential to calculate the opening stocks of atmospheric environmental resource assets, as the total profit and loss of the closing stocks in all provinces are relatively balanced and basically at the same order of magnitude, which is beneficial to determine ecological compensation standards.

Compared with rough grades in the urban air quality status, the SO_2 capacity resources assets and liabilities can provide specific profit or loss in physical and monetary terms for each region, which enable to quantify the government's occupancy and affordability of SO_2 capacity resources. Combined the closing values of stocks of capacity of SO_2 with economic development level, it can be inferred whether the industry and energy structures in one region are sound, strong and sustainable. The monetary accounts for SO_2 capacity resources may contribute to realizing the interest-balance of different economic subjects. In this case, it will be more feasible to carry out ecological compensation and off-office auditing. Moreover, it is possible to protect the atmospheric environmental resources by using the market economy instead of administrative coercive measures.

Through the methodology in the present paper, the physical and monetary accounts of atmospheric environmental resources can be calculated and integrated into natural resources balance sheet, which establishes a link between environment and economy. The following suggestions are proposed. First, the top-level design should be strengthened to issue rule systems with operational guidelines for the natural resources balance sheet and ecological compensation. Second, more meteorological parameters such as wind speed, wind frequency and atmospheric stability, should be monitored, recorded and released in order to improve the accuracy of the A-value method. Third, the emission trading system for pollutants should be stable and unified as a national system to provide a market price for pollutants that varies with the level of economic development and the environment. Only with more accurate physical accounts and more constant monetary accounts can we give full play to the role of natural resource balance sheet in improving environmental quality and supporting the challenging co-ordinated development of economy and environment.

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