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Original Research Paper

Application of Environmental Gini Coefficient (EGC) in Allocating SO_2 Discharge Permit: A Case Study of SO_2 Total Mass Control in Anshan, China

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ABSTRACT

The allocation of SO_2 discharge is always a challenge in total mass control due to the conflicts between environmental equality and efficiency. In this article, we introduced a way of allocating discharge by using Gini coefficient, a widely used index of income inequality in economics. The environmental Gini coefficient (EGC) method is based on a multi-criteria system, which includes land area, population, environmental capacity and gross domestic product (GDP). Through a linear programming optimization method, the regional pollutant reduction plan is optimized. The allocation of SO_2 discharge in Anshan, China was chosen as a case study to illustrate the application of this method. The result obtained shows that the application of EGC method and linear programming can make the allocation more fair and reasonable. Therefore, Anshan should adjust the structure of the industries as well as elevate the economy. At the same time, the environmental capacity of Anshan area should be improved by some measures.

INTRODUCTION

The allocation of SO_2 discharge that is demonstrated in this paper is part of the work of "the Chinese 12th five year air resource management plan", the word "efficiency" is based on economic consideration and also environment conservation. The permitted SO_2 discharge limit is limited, therefore the allocation of the discharge should be efficient, economic and fair. The conflict between efficiency and equality in distributing waste discharge permit is critical, given the need to balance environmental quality and economic growth. Therefore, we must take social, economic and environmental equalities into account when making decisions on allocating SO_2 discharge.

Unlike carbon dioxide, SO_2 may seriously affect people's life more under certain circumstances. Therefore, the allocation of SO_2 discharge should consider not only economic efficiency, but also social equality and environmental quality. On the other hand, grandfathering is a top-down method based on stakeholders' historical discharges. Being able to provide greater political control over the distributional effects of pollution regulation, grandfathering has been applied widely. Unlike the auction method, grandfath-ering schemes lead to efficiency losses if stakeholders increase their grandfathered amount by choosing higher emission levels. Böhringer criticized the static grandfathering schemes only, which are based on historical pieces of information by providing an optimized model in total mass allocation (Böhringer & Lange 2005). Mæstad (2007) proposed an approach on allocation of tradable emission (SO_2 and CO_2) permit to firms for international capital market. Unlike pure grandfathering, the permit distribution is based on the actual emission level of production and the amount of capital and labours used. The allocation of waste discharge permit has primarily focused on CO_2 emissions (MacKenzie et al. 2008, Schleich et al. 2006). In developing countries, resource management and environmental protection needs more attention, especially on social equality, economic development, and feasibility. In this research, a multi-criteria framework is proposed, which takes environmental benefit, economic development and social equality into account, for the allocation of SO_2 discharge by using the environmental Gini coefficient (EGC) method.

MODELS AND METHODS

Gini coefficient: The Gini coefficient, is usually a ratio between 0 and 1, and it is a commonly used economic measurement for income inequality or wealth distribution (Bosi & Seegmuller 2006). The lower the Gini coefficient, the higher equality the society attains. On the other hand, higher Gini coefficient implies less equality. The value of 0 means absolute equality while the value of 1 means absolute inequality. The Gini coefficient is calculated based on the Lorenz curve, a graph of cumulative percentage of household income on percentage of cumulative population with the population order being from lowest to highest income (Barr 1993). The Gini coefficient is equal to the ratio of the area *A,* to the area *A* plus *B* on the graph, as shown in Fig. 1. It could be calculated using the following equation (Brown 1994).

$$G_j = 1 - \sum_{i=1}^{n} (X_{j(i)} - X_{j(i-1)})(Y_i + Y_{i-1}) \quad ...(1)$$

X_i is the cumulative percentage of the population and Y_i is the cumulative percentage of household or income. When i=1, X_{i-1} and Y_{i-1} are both equal to 0. Gini coefficient has been widely used in studying the impacts of inequality, such as the impact of income inequality on health or the impact of income distribution on carbon tax in the U.S (Ellison 2002, Oladosu & Rose 2007). The Gini coefficient has also been used in the field of environmental management. For example, Heerink incorporated capital income Gini coefficient with an environmental Kuznets curve to estimate the environmental impact of income inequality (Heerink et al. 2001, Kuznets 1955). Moreover, Gini coefficient has also been used to study environmental inequality. For instance, Saboohi used Gini coefficient to analyse the distribution of energy consumption and also used it to study the inequality between urban and rural neighborhoods in Iran (Saboohi 2001). Jacobson et al. (2005) used the Gini coefficient of residential energy consumption to analyse the electricity consumption distribution and inequality in five countries and found a dramatic range of energy distributions that, industrializing countries generally have higher inequality than industrialized countries. White used Gini coefficient to study the share of global ecological footprint and claimed that measuring the distribution of natural resource use will be necessary to achieve a society that is sustainable and efficient and suggested that the reduction in energy use by nations who are currently heavy users will lead to not just a more sustainable, but also more distribution of the global ecological footprint (White 2007, Moffatt 2000). Finally, Area-Based Gini Coefficient (AR-Gini) is a measurement of resource inequality by areas. It is different from the conventional Gini coefficient in two ways. First, it measures inequality in terms of the mass of resources rather than monetary transactions. Second, AR-Gini is calculated on an area basis, giving a measure of inequality by comparing the resource uses of neighborhoods, whereas the conventional Gini coefficient compares the household or per-capita basis. In this research study, the Lorenz curve would be used in the allocation of discharge permits. While the multi-criteria that can represent local economical, social and natural condition is on the *x*-axis; the exhaust gas discharge permits is on the *y*-axis.

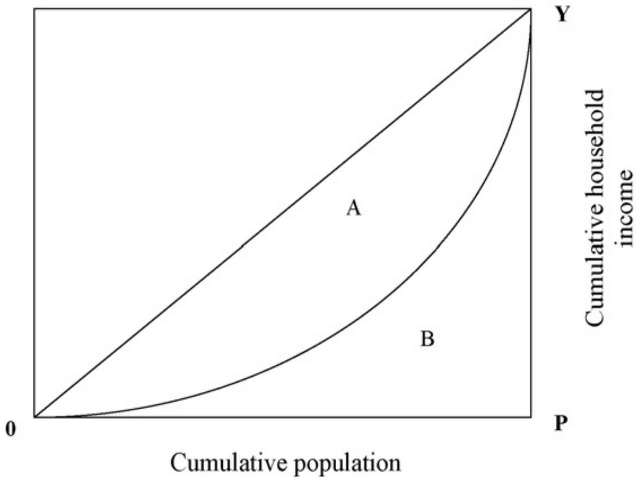

Fig. 1: Calculation of Gini coefficient using the Lorenz curve.

Multi-criteria based Gini coefficient: In this research, multi-criteria were chosen to represent both "efficiency" and "equality". If the EGC of the permit distribution gets smaller, the distribution would have higher equality and efficiency. As EGC uses grouped data from districts instead of from each individual point source in the calculation of the Gini coefficient, EGC method is very similar to the method of AR-Gini, which was used as an index to measure resource inequality for different areas (Druckman & Jackson 2008). Additionally, in this paper, EGC expands the original Gini coefficient from single criteria to a multi-criteria system based on indicators reflecting economic, ecological and social concerns. There are three criteria chosen in the EGC method, these include: population, land area and gross domestic production (GDP).

Population is a social index. As mentioned earlier, the SO_2 discharge permit is a public resource or common wealth, so each person in the district has equal rights. In the Lorenz curve, population of each district is on the *x*-axis, and SO_2 discharge is on the *y*-axis. The minimization of this Gini coefficient would make the people get equal share of the discharge permits, which is satisfied by the principle of "equality".

GDP is a widely used economic index that can represent local economic development. One meaning in the principle of "efficiency" is that, the discharge permit allocation would encourage the improvement of the efficient "resource" consumption. So in the allocation, every district is treated as an "entire company". Based on their history date, GDP is on *x*-axis while SO_2 discharge is on *y*-axis of the Lorenz curve. The minimization of this Gini coefficient means that the allocation of SO_2 discharge permits will be based on the portions of GDP. Also, the district with higher "resource" efficiency could get more shares of discharge permits than its

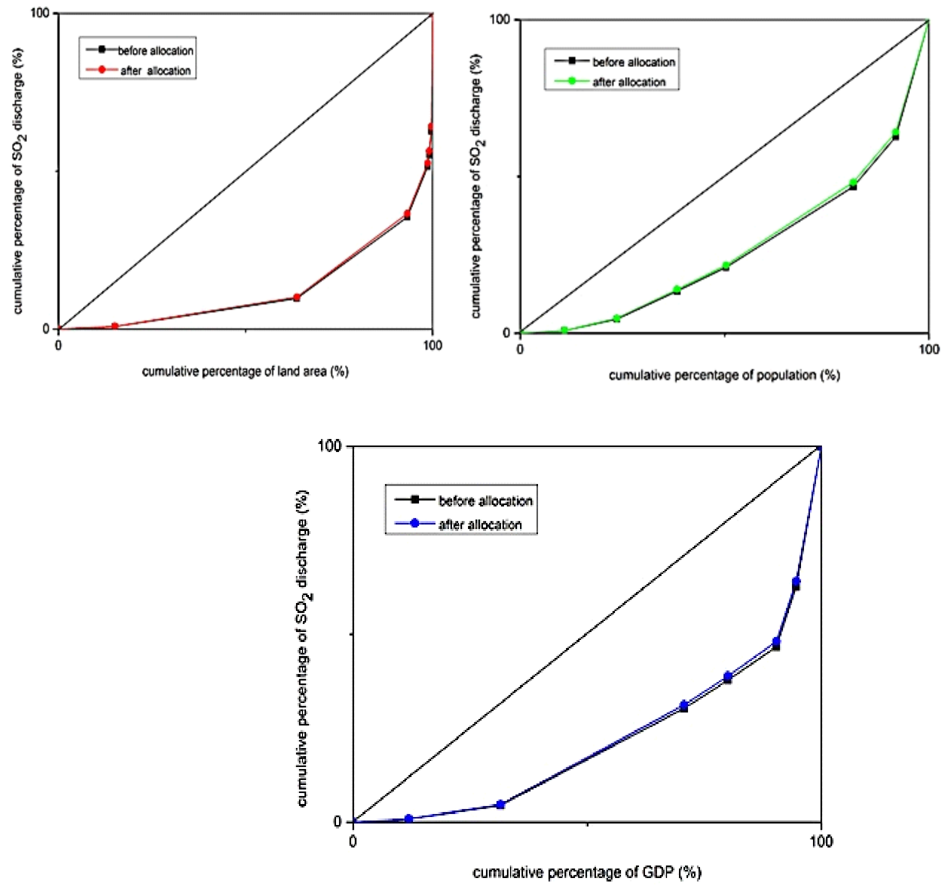

Fig. 2: Comparison of the optimization results based on the three criteria.

current waste discharge. On the other hand, the economic development is one of the most important issues the local governments care about.

Land area is the index that should be put into Gini coefficient with future consideration. In the Lorenz curve, the *x*-axis is the land area of each district and the *y*-axis is SO_2 discharge. The minimization of this Gini coefficient will lead to an equal share allocation of discharge permits based on district's land area. Therefore the larger land area often means the district has development potential in population or industry or economy, and has more environmental capacity.

Character of allocation method: The EGC allocation method is different from the economic Gini coefficient method in the following three ways. First, the permit allocation process is an optimization based on current situations. Each district makes a reduction of SO_2 discharge based on its current discharge load. Current population, GDP, and land area are also used in the optimization. The EGC method is a modification of grandfathering in a way that the SO_2 discharge permit is distributed to each district using historical data on environmental efficiency and equality.

Second, the consequence of districts' SO_2 discharge per criterion should be constant after optimization. In the calculation of Gini coefficient, the date should be in order, starting from the lowest to highest. The EGC calculation requires the districts' SO_2 discharge per criterion in an order from lowest to highest. This order should be the same before and after the SO_2 discharge reduces to satisfy total mass control. For example, the order of SO_2 discharge per population does not change after optimization, so as those of GDP, land area and population. This rule comes from the consultation with local EPB and stakeholders. If the consequence of districts in the EGC changes, some districts should make more reduction on their SO_2 discharge than they could in 5 years (2010-2015). Besides, an upper limitation for the waste discharge reduction rate of 10% and a lower limitation of 1% are set for each district to make sure that each district has SO_2 discharge reduction but not beyond its capability (Sun et al. 2010). Finally, the target of the allocation optimization is to get the minimum total EGC of multi-criteria.

Meanwhile, the EGC for each criterion would not get larger, due to the fact that no more inequity will be brought into each criterion in the optimization.

Allocation steps: In a nutshell, after determination of the object of total mass control, the allocation process could be described as an optimization, which includes the following four steps.

1. Conduct a pilot study on the current SO_2 discharge as the initial condition for the optimization.
2. Compute the Lorenz curve of current SO_2 discharge by using the three criteria to calculate the EGC.
3. Based on the given SO_2 discharge reduction rate, optimize the allocation of the SO_2 discharge permits for each district to get the minimum summation of EGCs of each criterion. The optimization has several constraints. For example, SO_2 discharge permits should satisfy the plan of total mass control. Each EGC only becomes smaller in the optimization. The SO_2 discharge reduction rate of each district is within the upper and lower limit. The consequence of the districts in each Lorenz curve is unchanged after the optimization. The optimization process can be described by the following equations (Groves-Kirkby et al. 2009).

   Optimization object: $\min\sum_{j=1}^{3} G_j$

   $$G_j = 1 - \sum_{i=1}^{n} (X_{j(i)} - X_{j(i-1)})(Y_i + Y_{i-1}) \quad ...(2)$$

   Constraints to

   Total mass control of waste discharge:

   $$P = W \times (1-q); \quad ...(3)$$

   Constrain of each Gini coefficient:

   $$G_j \le G_{0(j)};$$

   Waste discharge reduction rate of each district:

   $$S_i = (1 - p_i) \cdot S_{0(i)} \quad ...(4)$$

   $$p_{i0} \le p_i \le p_{i1}$$

   The consequence of the districts in the Lorenz curve:

   $$K_{j(i)} = \frac{S_i}{M_{j(i)}}$$

   $$K_{j(i-1)} \le K_{ji} \le K_{j(i+1)} \quad ...(5)$$

   Where G is the Gini coefficient; j is one of the three criterions of EGC; i represents the number of the districts in the study area; G_j is EGC for criterion j after the optimization; $X_{j(i)}$ is the accumulative percentage of criteria j of the ith district; Y_i is the accumulative percentage of waste discharge after reduction and optimization, which is the discharge permit of the ith district; $S_{0(i)}$ is the current waste discharge of the ith district, $G_{0(j)}$ is the original Gini coefficient of criteria j with current waste discharge; p_i is the waste discharge reduction rate for the ith district; p_{i0} and p_{i1} are the lower and upper limit of the waste discharge reduction rate for each district; $M_{j(i)}$ is the value of criteria j in the ith district; $K_{j(i)}$ is the waste discharge permit per unit of criteria j in ith district after the allocation.
4. Discuss the optimization result with local EPBs of the district and the stakeholders to confirm its feasibility. If the result is not acceptable, the reduction rate should be adjusted and the optimization process repeated. Fig. 2 shows the comparison of the optimization results based on three criteria.

RESULTS

Environmental Gini coefficient of multi-criteria before allocation: In 2011, the SO_2 discharged was 110503.402 tons in Anshan. According to the 12th Five-Year Plan, a series of national economic development initiatives established by the Chinese central government in each 5 years, to 2015, reveals that SO_2 discharge should reach a 6.5% reduction based on the discharge in 2010. Anshan is divided into 7 county-level districts to which the total mass control permit is distributed. This research demonstrates how the discharge permits of 2015 are distributed to each district using the EGC method. The data for SO_2 discharge came from Anshan EPB while the data for GDP, land area and population were obtained from National Bureau of Statistics of Anshan.

First, the Lorenz curve was drawn and calculations of EGC was based on 2011 SO_2 discharges of the districts. Taking the land area EGC as an example, the result obtained is given in Table 1. From the table, it is observed that the EGC of the land, population and GDP are greater than 0.4. We found that EGC of population is the smallest, which means the SO_2 discharge distribution to districts, is more done by population than by any other criterion. This can be explained by the fact that, as a typical industrial and mining city of China, more than 60% of SO_2 discharge in Anshan comes from waste gases created by residents' daily consumption and industrial pollution (industrial waste gases). The Lorenz curve of SO_2 discharge based on multi-criteria before allocation is shown in Fig. 3.

Environmental Gini coefficient of multi-criteria after allocation: Optimizing each criterion with constraints, considering the total reduction rate of pollution discharge in the whole area of Anshan is q=6.5%, the Anshan Municipal Environmental Protection Bureau after discussion with various districts and counties, decided to set the upper limit of the total pollution discharge reduction rate as 10% and 1% for the lower limit of the total pollution discharge reduction

Table 1: Calculation of SO_2 discharge Gini coefficient based on land area of year 2011.

Districts	Land area (km^2)	SO_2 discharge in 2011(t/year)	Slope	Cumulative percentage of		Gini coefficient
				Land area	SO_2 discharge in 2011	
Taian	1394.74	898.376	0.644	15.07%	0.81%	0.0012
Xiuyan	4502.20	9877.33	2.19	63.71%	9.75%	0.0514
Haicheng	2732.82	28467.434	10.42	93.24%	35.51%	0.1337
Qianshan	505.53	17608.663	34.83	98.70%	51.45%	0.0475
Tiedong	41.77	4077.584	97.62	99.15%	55.14%	0.0048
Lishan	48.41	8360.636	172.70	99.68%	62.70%	0.0062
Tiexi	29.89	41213.379	1378.84	100%	100%	0.0052
Total	9255.36	110503.402				

Table 2: Environmental Gini Coefficient of multi-criteria.

Criteria	Land area	GDP	Population	Total
Before optimization	0.7500	0.5838	0.4675	1.8013
After optimization	0.7424	0.5566	0.4551	1.7541
Difference	0.0076	0.0272	0.0124	0.0472

Table 3: Allocation of the SO_2 discharge permit in districts.

Districts	SO_2 discharge in 2011(t/year)	Discharge reduction rate (%)	Pollutant reduction (t/year)	Discharge permit in 2015 (t/year)
Taian	898.376	1%	8.984	889.392
Xiuyan	9877.33	3.35%	330.891	9546.439
Haicheng	28467.434	3.93%	1118.77	27348.664
Qianshan	17608.663	6.35%	1118.15	16490.513
Tiedong	4077.584	2.08%	84.95	3992.634
Lishan	8360.636	4.78%	399.638	7960.998
Tiexi	41213.379	10%	4121.338	37092.041
Total	110503.402	6.5%	7182.721	103320.681

rate. Table 2 shows EGC of each criterion before and after the optimization where the EGC based on land area is 0.7500, EGC based on population is 0.4675 and the EGC based on GDP is 0.5838. After optimization, the sum of EGC decreases from 1.8013 to 1.7541. From this result we observed that the change of Gini coefficient of each criterion was not big. Hence, the biggest change of Gini coefficient noted was that of GDP, with a rate of 0.0272. The change of the land was very small, but we can achieve the reduction target of 6.5% if the optimization result of the environmental Gini coefficient is adjusted to equitable interval defined in economics. In addition, if the reduction rate is greater than 6.5%, the allocation schemes will have no significance in five years. The discharge reduction rate is different from the pollutant discharge before allocation as given in Table 3. This is a comprehensive consideration of various districts of the natural, economic and other objective factors. The environmental Gini coefficient method is relatively the most equitable distribution of the program based on the unit of index system (unit population, unit GDP, the unit of land area) after allocation.

Fig. 4 shows the Lorenz curve of the multi-criteria system after allocation. It is clear that the EGC and the Lorenz curve does not change very much after the optimization, because the criteria like population and GDP are not distributed to each district equally and the order of districts in Lorenz curves are not the same. Moreover, there are upper and lower limits on SO_2 discharge reduction to each district. Considering constraints in the EGC method, the shape of the Lorenz curve can only be adjusted gradually, which is why the EGC does not have a large variation after the optimization.

DISCUSSION

Contrasting the allocation plan and the status of pollution control, the allocation plan is consistent with the actual pollution control ability. Fig. 5 shows the distribution of eco-

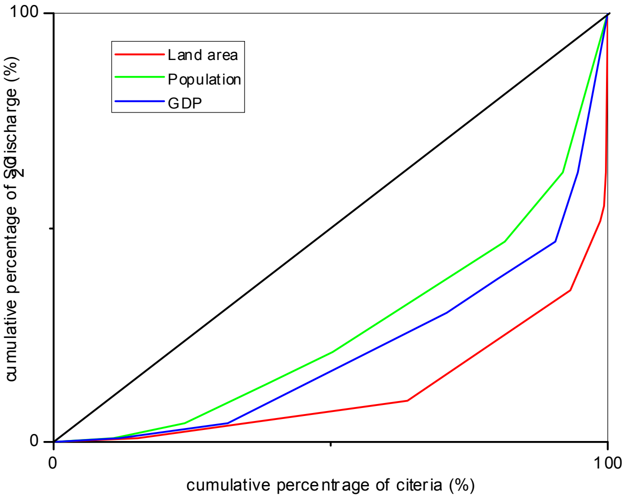

Fig. 3: Lorenz curve of SO_2 discharge based on multi-criteria before allocation.

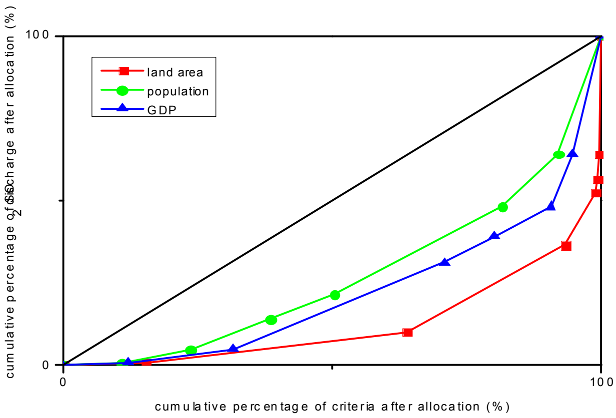

Fig. 4: Lorenz curve of SO_2 discharge based on multi-criteria after allocation.

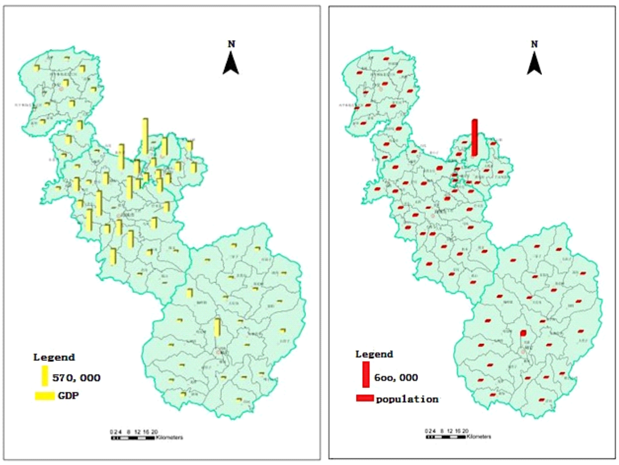

Fig. 5: The distribution of economic development and population in Anshan City.

nomic development and population in Anshan City. For example, the total amount of pollution discharge of Haicheng and Tiedong districts is very large, the unit population bearing capacity is relatively large. But the regional economy is developing, pollution control facilities are perfect, and the pollution control is very efficient. From the perspective of fairness, we can relatively cut small proportion. Tiexi region has serious pollution and relatively weak economic development. The environmental capacity is very small, so we should adjust the industrial structure and cut a large proportion. For the Qianshan and Xiuyan districts, the total discharge of pollutants is not the largest, but due to the relatively backward economy, the pollution control facility is not perfect, therefore, the pollution control efficiency is low, and the environmental capacity is relatively small. So we should relatively cut a large proportion.

We can see by the calculation that the greatest distribution inequity occurs in the land area with EGC equal to 0.7500. The high Gini coefficients explain that the distribution of SO_2 discharge sources do not fit the natural condition very well. The natural self-purification capability is not effectively occupied in some districts or over-occupied in others; it has the lowest measure of fairness of all the factors in the three criteria. This is mainly due to the intensification of Anshan caused by land. The industrial and mining areas are mainly located in the city proper. Anshan Iron and Steel Company are mainly located in Tiexi district, Tiedong district and Qianshan district and partially located in Lishan district in Anshan. This leads to greater emissions of SO_2 in the smaller area and therefore leading to the unfairness based on land. So Anshan should adjust the structure of industries as well as elevating the economy.

After the Gini coefficient calculations, it was observed that, the districts of largest reduction rate are Tiexi, Qianshan and Lishan. The percentage of SO_2 emission in Anshan Iron and Steel Group recorded 33.1%, and the percentage of SO_2 production in Anshan Iron and Steel Group recorded 32.1%. So Anshan Iron and Steel Group make the main industrial pollutant of SO_2. Hence, it is very important to strengthen the work of cleaner production and pollution prevention of Anshan Iron and Steel Group. The discharge of SO_2 is mainly due to ore-sintering plant and ironwork at Anshan Iron and Steel Group. Therefore, the reasonable control of ore-sintering plant and iron work's SO_2 emission is very important. In this way, we can reduce the SO_2 emission of Anshan Iron and Steel Group and the discharge of SO_2 at Anshan will be reduced. The environmental Gini coefficient based on land will be smaller and the SO_2 distribution will be more reasonable.

Anshan is a representative of an old industrial city within

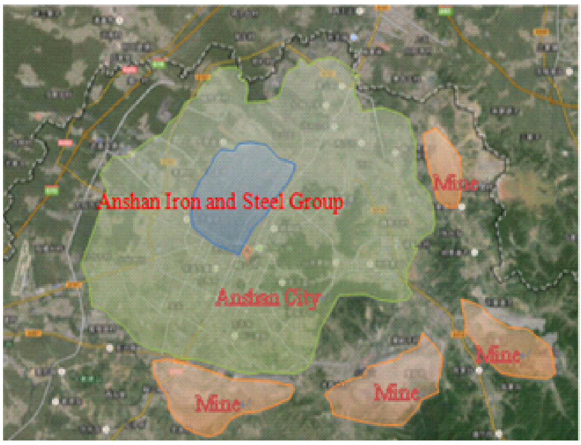

Fig. 6: The city space layout of Anshan.

the interim of industrialization and urbanization that is capable of achieving transformation in industrial structure and also in reducing industrial pollution at a greater degree.

Fig. 6 shows the city space layout of Anshan. The industrial developments' present situation and future development trend makes Anshan different from Pittsburgh, which has achieved great development mode transformation by increasing environmental capacity of Anshan City. For example, increasing space capacity: By adjusting the urban, industrial layout and outfall, so that Anshan can use a larger environmental capacity; increasing capacity by improving efficiency: Through the transformation of traditional industries; improving management level and market economic instruments, increasing the output efficiency per unit of environmental capacity.

According to the size of environmental Gini coefficient in every district and from the three criteria given, the unfair factors of the regional development were analysed. This made it possible to make some measures that increased environmental capacity thereby increasing the amount of Anshan City and environmental health risk zoning classification. In this way, the formation of interaction between the overall planning of the city and the industrial planning can be achieved. In this way, it is then possible to improve the environment and control the pollution without affecting the city's construction and economic development.

CONCLUSION

The Gini coefficient is a widely used economical index for income inequality, it was first used in environmental management as an indicator of inequality of resource use. This research introduces EGC as an indicator of waste discharge inequality and then develops it as a method for SO_2 discharge permit allocation. The method is based on the idea that waste discharge is a kind of resource and equality, which is an important concern in the waste discharge allocation as well as efficiency. In the optimization, current SO_2 discharge is regarded as the initial condition, so the allocation is based on historical data of discharge. Therefore, the allocation is a modification of grandfathering. There are three different EGCs based on the multi-criteria, minimizing all of them is a multi-objective optimization process. Traditionally, constructing a single aggregate objective function can solve these problems. However, in creating a single combination the main objective is to represent the three EGCs as a key point. In the allocation process, we cannot tell which criterion is more important than the others; hence the equal weight aggregate objective function was used.

The application of environmental Gini coefficient (EGC), in allocating SO_2 discharge permit in Anshan, is a completely different single factor allocation method. Environmental Gini coefficient can put health factors, space layout and economic development into consideration. The main target is to adjust the industrial layout and make the regional pollutants more and more fair.

In this research study, three criteria were chosen to solve the problem in SO_2 discharge allocation. Putting forward the constraint after fully considering the objectives, conditions and influence factors in SO_2 discharge allocation in Anshan; we then came up with a method that can only choose one or two indicators to optimize results. In this way, the operability of the final optimization of the conditions can be improved.

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