

# Performance evaluation on air pollution reducing facilities and mechanism research on the third-party governance on environmental pollution

**Xu Bingsheng, Lin Ling,\* Huang Jin, Wang Geng, Chen Jianhua, Yang Shuo, Guo Huiting**

China National Institute of Standardization, No.4, Zhichun Road, Haidian District, Beijing 100191, China

dengdaitianqingdeyu@126.com

**Abstract.** The paper focuses on developing the operational efficiency of air pollution reducing facilities and the treatment effect of the third-party governance on environmental pollution. Comprehensive analysis method and influence factor analysis are employed to build an evaluation index system by means of discussing major pollution control factors derived from the performance of pollution control equipment operation, environmental protection, technological economy, recourse consumption and manufacturing management. Based on the pattern of environmental pollution control offered by the third-party company, the static games model is further established between the government and the pollution emission firm by considering the whole process of the pollution abatement including investment, construction and operation of the treatment project, which focuses on establishing the policy condition and consequence by discussing the cost and benefit in a short and a long time, respectively. The research results can improve the market access requests of the pollution control equipment and normalize the environmental protection service offered by the third-party company. Moreover, the establishment of the evaluation index system for pollution control equipment and the evaluation mechanism for the third-party governance on environmental pollution has guiding significance on leading environmental protection industry and promoting market-oriented development

## 1. Introduction

The third-party governance over environmental pollution is a new mode that pollution emitters make payments as per the contract agreements to entrust environmental service companies for pollution control, which successfully shifts the traditional principle of pollution control from “who pollutes, who governs” to a new market operational mechanism of “who pollutes, who takes responsibilities, and the third-party governs” [1].

In developed countries, this mode to introduce the third party in project construction is relatively mature, but it is more extensively used in developing countries in recent years [2]. With this mode, Japan have made remarkable achievements in environmental pollution control as it puts emphasis on the joint participation of governments at all levels, enterprises, social organizations and citizens [3]. The central and local governments take charge of setting up policies and standards as well as supervising and assessing the implementation of these policies. Otherwise, governments approve the qualifications of enterprises engaged in the third-party governance on environmental pollution (herein after referred to as “TGEP”) and will give preferential policy including extending the validity of the



industry permit and so on. The third-party enterprise is required to properly master the progress of entrusted affairs and to timely submit declarations, records and relevant reports to the entrusting enterprise after completing the program. All above measures standardize the market behaviors of both suppliers and demanders and provide an institutional guarantee for effective implementation of TGEP mode in the environmental protection industry.

In China, the socialized operation ratio of industrial pollution control facilities is relatively low, which is only around 5% [4]. It is difficult to objectively assess the operating effectiveness of pollution control and renovation projects due to lack of fair and reasonable performance assessment mechanism, as well as technical standards for measurement and verification of pollution control efficiency. There is no scientific basis for relevant supporting policies, and no effective and reasonable TGEP mode is formed. Moreover, the responsibilities of pollution emitters and the third party enterprises are not definitely clarified, which significantly affects the enthusiasm of the pollution control demanders to introduce the third-party governance mode. Meanwhile, financing supports of third-party pollution governance in China faces great difficulties due to lack of scientific and reasonable evaluation mechanism, and it is impossible to guarantee the reasonable and effective use of financial funds, as well as the project benefits, which further hinders the development of the TGEP mode [5].

Therefore, in consideration of imperfect mechanisms as well as incomplete laws and policies regarding third-party governance over environmental pollution, it is urgent to standardize the TGEP mode in order to improve efficiency of pollution control and to develop technological advantages of environmental pollution controllers through the research on performance evaluation on pollution reducing facilities, so as to provide fundamental mechanism for reduction of pollution and protection of ecological environment [6].

This paper studies the methods for evaluation of generality of efficient environmental protection equipment for air pollution control on the basis of the TGEP mode. Desulphurization, dust removal and denitration systems are chosen as the evaluation object, and the indicator system is further set up by screening key evaluation indexes. Based on the static games model [7], incentive evaluation mechanism is designed by discussing the cost and the benefit of the government, the pollution emission firm, and the service firm for third-party governance on environmental pollution, which is proposed to ensure the effective execution of the TGEP mode and to normalize the environmental protection service offered by the third-party company.

## **2. Research Basis**

### *2.1. Methods*

As for evaluation of generality of efficient environmental protection facilities for air pollution control, comprehensive analysis and site investigation methods are applied to screen and determine the primary and secondary evaluation indicators through studying on technical data, standards and policies. The technical requirements for evaluation system should comprise both qualitative and quantitative evaluation indicators. Comprehensive evaluation method is adopted for quantitative evaluation of performances of flue gas desulfurization, dust removal and denitration systems with kinds of indicators. On this basis, cost-benefit analysis method is introduced to analyze the investments and returns of the government, pollution emitters and pollution controllers during the whole process of pollution control projects [7]; statistic game model is employed to determine the conditions and results of third-party environmental pollution strategies introduced by the government, pollution emitters and pollution controllers in a short-term and a long-term games, respectively. Finally, a reasonable and incentive evaluation mechanism is proposed for the implementation of the TGEP mode.

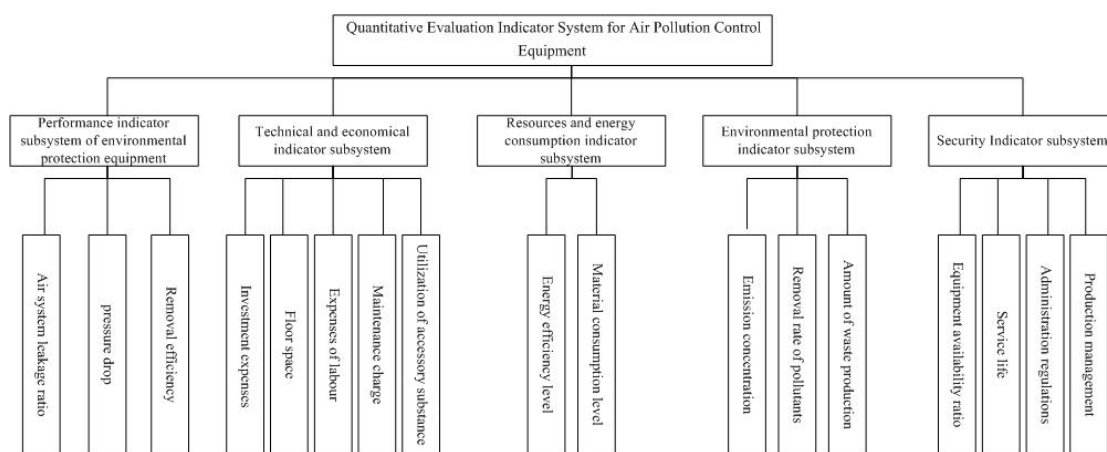
### *2.2. Establishment of Evaluation Indicator System*

The evaluation indicator system for efficient air pollution control facilities is established based on laws, regulations, rules, technical polices and plans of China regarding environmental protection and

pollution control to promote the harmonious development of environmental, economic and social benefits. The establishment of evaluation indicator system and determination of main evaluation indicators involve pollution control projects with the participation of pollution emitter and controllers. Therefore, the capacities of the manufacturers and users' interests should be fully considered, and key factors with significant impact on production and operation of air pollution control facility are selected as evaluation indicators derived from considering technical performance, energy-saving and environmental protection, safety and reliability of pollution control facilities, which can provide guidance for the mode of third-party governance over environmental pollution in China.

In this paper, preliminary researches are performed for dozens of electrostatic fabric filter, electric filter, bag filter, and desulfurization and denitration equipments provided by manufacturers, users and design companies. Relevant technical literatures are reviewed and analyzed. A great deal of technical performance data, energy efficiency data and environmental protection data of air pollution control facilities are extensively collected by sampling and surveying the information regarding control technologies, energy consumption and pollutants, so as to preliminary determine the scope of primary and secondary evaluation indicators. In addition, it is proposed to evaluate the energy-saving, environmental protection, safety and comprehensive operation performances of integrated systems in operation.

The qualitative evaluation indicators focus on the management level of manufacturers, the quality level of air pollution control equipments, the technological level with low resource consumption and low pollutant emission and comprehensive measures of fully utilizing the wastes and by-products to minimize the resource and energy consumption and to improve the resource and energy utilization rate. Besides, the quantitative evaluation indicators should comprise primary indicators and secondary indicators, as shown in Fig. 1. The primary indicators include technical performance indicator, technical & economic indicators, resource & energy consumption indicators, environmental protection indicators and safety & reliability indicators that can be further divided into several secondary indicators. As the types of equipment are different, the indicators may be chosen and adjusted as per the specific conditions. The evaluation values for secondary indicators of various efficient air pollution control equipment will be set in accordance with their overall level to ensure that evaluation values of all secondary indicators are of advanced level in air pollution control equipment industry in China.



**Figure 1.** Quantitative Evaluation Indicator System for Air Pollution Control Equipment

Specifically, the evaluation indicators must be chosen in full consideration of their representativeness. As there are numbers of parameters for evaluating air pollution control facilities, the evaluation indicator system should be established by selecting several most important key parameters according to features of different types of air pollution control equipments. The score for evaluation can be equally divided into four classes: excellent, Class I, about 20% out of the total

number; poor, Class IV, about 10% out of the total number, to be rectified or deprecated; good, Class II, about 40% out of the total number; and General, Class III, about 30% of the total number.

### 3. Research on Evaluation Mechanism

Evaluation mechanism is an important guarantee for the efficient and continuous evaluation of the TGEF mode. This paper designs an incentive evaluation mechanism, which is established by forming a game model between pollution emitters and controllers through cost-benefit analysis on the pattern of the third-party governance over environmental pollution on the basis of evaluation indicator system mentioned above, and proposes an evaluation procedure that can keep the evaluation of the TGEF mode feasible and ensure the effective application of evaluation model.

#### 3.1. Cost-Benefit Analysis

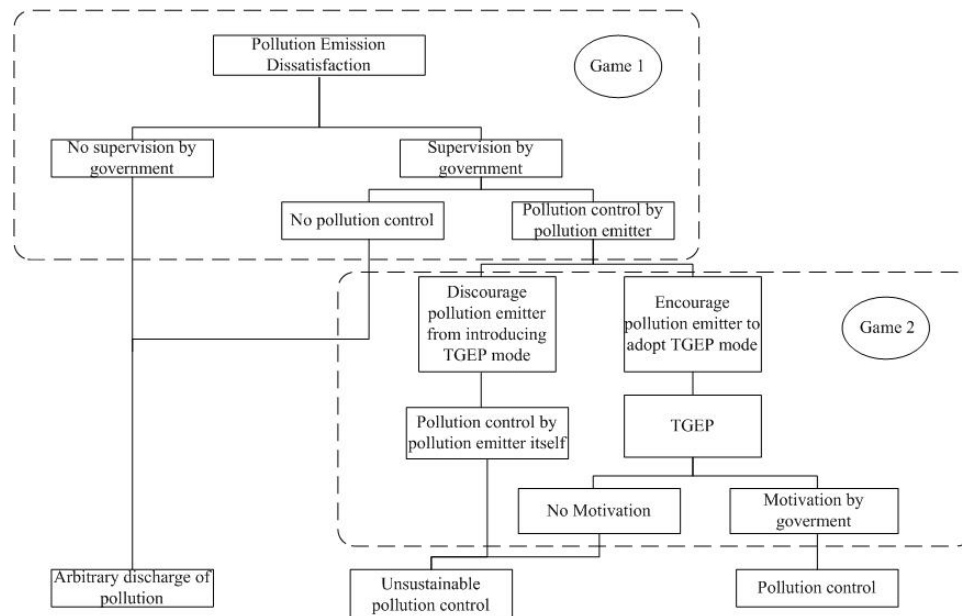
Under the mode of third-party governance over environmental pollution, all enterprises are classified as the pollution emitters and controllers. Costs for environmental pollution control from the pollution emitters mainly comprise the following items: first, construction cost  $E_{cc}$ , i.e. costs incurred by pollution emitters to manage construction projects with pollution control; second, investment cost  $E_{ic}$ , mainly including costs for entrusted project services input by pollution emitters in entrusting or hosting projects; third, price cost  $E_{pc}$  i.e. costs come from penalty or punishment under the condition of pollutant emission requirements are not met; fourth, expenses for purchase of emission permits  $E_{ep}$ . Revenue obtained by the pollution emitters include revenues obtained from emission permit trading or shared benefits with pollution controllers  $R_{mp}$ , as well as honors good for the corporate image obtained due to remarkable achievements in pollution control  $R_{hr}$ . Costs of the third-party pollution controllers serving the pollution emitters include the following items: first, construction cost  $T_{cc}$ , i.e. construction, operation and maintenance costs incurred in the process of serving for the pollution emitters; second, price cost  $T_{pc}$ , any compensation or punishment from pollution controllers when the effect of services fails to satisfy the contractual requirements or the pollution emitters suffer losses as the pollution emission requirements are not satisfied. In addition, there is another type of price cost  $T_b$ , i.e. the pollution emitter is blacklisted due to poor pollution control performance. Moreover, the pollution controllers may not be directly punished by the government due to unqualified pollution control, as the pollution emitter is the subject of responsibility. The revenues obtained by the third-party pollution controllers include: first, revenues obtained from emission permit trading shared with pollution emitters  $R_{mp}$ ; second, policy bonuses of green credit support, tax preference, green bonds, environmental protection fund, etc. provided by the government for long-term excellent performance in pollution control services  $R_{pr}$ ; third, honors good for the corporate image  $R_h$ ; fourth, emission reduction project construction fees paid by the pollution emitters under the contract  $R_{ic}$ .

As the regulatory department for pollutant discharge, the government is obliged to guide the environmental pollution control behaviors and overall manage the pollutant discharge. Therefore, costs for the government include: first, system cost  $G_{sc}$ , i.e. costs relating to formulation of various policies for supervision, assessment and evaluation of environmental pollution control; second, regulatory cost  $G_{rc}$ , also called system implementation costs, i.e. costs relating to the site investigation, evaluation and assessment of pollution control behaviors of the enterprises; third, incentive costs  $G_{ic}$ , i.e. policy bonuses granted to pollution controllers with excellent performance in pollution control after assessment, including costs relating to possible tax preference, capital support, subsidies, etc. Besides, the revenues of the government include revenues from taxes  $R_t$ , penalties  $R_p$ , environmental performance  $R_e$ , as well as honors for effective improvement of environment  $R_h$ .

#### 3.2. Game Model for Implementation Mechanism of Third-party Governance over Environmental Pollution

It can be seen that there are several game relationships among pollution emitters, pollution controllers and the government by cost-benefit analysis, and improper selection of any of them may result in poor

pollution control performance. The model for game between the government and pollution emitters as well as the third-party pollution controllers is shown in Fig. 2.



**Figure 2.** Analysis on Game Behaviors between the Government and Pollution Emitters as well as Pollution Controllers

There are two kinds of games between the government and enterprises, represented by different game behaviors respectively. To simplify the model, it is assumed that pollution emitters can choose from “no pollution control” or “pollution discharge control by pollution emitter” only, while the “pollution control” can be further divided into “self-governance” and “third-party governance”. “pollution control” is a kind of professional and efficient third-party governance mode actively input and introduced by pollution emitters, i.e. the right line for decision of the enterprise. “Arbitrary discharge of pollution” represents that the enterprise gets out of the responsibility for emission reduction or fails to actively control pollution discharge, generally the left line for decision of the enterprise. Similarly, it is assumed that there are only two options for the government, i.e. “supervision” and “no supervision”. Among them, “supervision” refers that the government takes certain supervision and encouragement methods to promote the enterprises satisfy the emission standards, as shown by the right line in the figure 2. “No supervision” refers that the government does not interfere the enterprises’ off-standard pollution discharge but takes no action, as shown by the left line.

There is a certain amount of time interval between the investment and the return of environmental pollution control projects. In this paper, static game analyses are performed for “a short-term” and “a long-term” cases.

**3.2.1. Game between the Government and the Pollution Emission Enterprise regarding Pollution Control in a Short Term.** Where pollution emitters do not control the pollution, the costs is the lesser between  $E_{pc}$  and  $E_{ep}$ , i.e.  $\min(E_{pc}, E_{ep})$ , while the revenue is  $R_{mp}$ ; where pollution emitters control the pollution, the costs is  $\min(E_{cc}, E_{ic})$  in a short term, which refers that independent pollution control, and the TGE mode (entrusted control or hosted control) will be chosen based on the actual costs, and the revenue is  $R_{mp} + R_{hr}$ . Where the third-party pollution controller refuses to control the pollution, the costs of pollution emitters are  $E_{ic}$  or  $E_{cc}$ , the pollution control costs of the third-party pollution controller are  $T_{pc}$ , and the revenue is 0. Where the pollution controller agrees to control the pollution, the cost of pollution emitters is  $E_{ic}$  or  $E_{cc}$ , the cost of third-party pollution control enterprise is  $T_{cc}$ , while the revenue is  $R_{mp} + R_{hr} + R_{pr}$ .



For the government, the cost is 0 and the revenue obtained is  $E_{pc}$  if the government chooses “no supervision”; or the government chooses “supervision”, the cost is  $G_{sc}+G_{rc}+G_{ic}$ , while the revenue obtained is  $R_e+R_h+R_t$ . Where,  $R^*$  is the actual tax after tax exemptions and reductions, which can be set as 0 in a short term.

The complete information static game model is applied to analyze the relationship between the government and the pollution emission enterprise in a short term, i.e. it is assumed that the revenue of the pollution emission enterprise from policy bonus and the incentive costs paid by the government are 0. Corresponding payment matrix is shown in Table 1.

**Table 1.** Payment Matrix for Complete Information Static Game between the Government and Pollution Emitters in a Short Term

	Pollution Control ( $\alpha$ )	No Pollution Control ( $1-\alpha$ )
Government Regulation ( $\beta$ )	$R_t^*-(G_{sc}+G_{rc}), R_{mp}-\min(E_{cc}, E_{ic})$	$R_t^*+E_{pc}-(G_{sc}+G_{rc}), R_{mp}-\min(E_{pc}, E_{ep})$
No Government Regulation ( $1-\beta$ )	$R_t, R_{mp} - \min(E_{cc}, E_{ic})$	$R_t, R_{mp}$

The static game model equation has a unique solution when the value of  $R_t^*+E_{pc}$  less than the value of  $G_{sc}+G_{rc}$ , and the equilibrium solution is  $(R_t, R_{mp})$ . In this condition, the payment cost of the government used for environment supervision is too high, which is contrary to the purpose of pollution control.

When the value of  $R_t^*+E_{pc}$  is larger than the value of  $G_{sc}+G_{rc}$ , the mixed decision-making game model can be introduced to derive the expectation functions of the government and the pollution emission firm, respectively.

$$f_1 = \beta\{\alpha[R_t^*-(G_{sc}+G_{rc})] + (1-\alpha)[R_t^*+E_{pc}-(G_{sc}+G_{rc})]\} + (1-\beta)[\alpha R_t + (1-\alpha)R_t] \quad (1)$$

$$f_2 = \alpha[R_{mp}-\min(E_{cc}, E_{ic})] + (1-\alpha)\{\beta[R_{mp}-\min(E_{pc}, E_{ep})] + (1-\beta)R_{mp}\} \quad (2)$$

Eq.1 and Eq.2 can be transformed by the method of derivation as follows

$$f_1' = (1-\alpha)E_{pc}-(G_{sc}+G_{rc}) - R_t + R_t^* \quad (3)$$

$$f_2' = \beta\min(E_{pc}, E_{ep}) - \min(E_{cc}, E_{ic}) \quad (4)$$

when  $f_1' = 0$  and  $f_2' = 0$ , and then

$$\alpha = 1 - [(G_{sc}+G_{rc}) + R_t - R_t^*] / E_{pc} \quad (5)$$

$$\beta = \min(E_{cc}, E_{ic}) / \min(E_{pc}, E_{ep}) \quad (6)$$

Combined with Eq.1-Eq.6, it concludes that  $(1 - [(G_{sc}+G_{rc}) + R_t - R_t^*] / E_{pc}, \min(E_{cc}, E_{ic}) / \min(E_{pc}, E_{ep}))$  is the equilibrium solution of the above game model. In other words, the equilibrium of decision-making model is closely related to the value of  $G_{sc}+G_{rc}$ ,  $R_t$ ,  $R_t^*$ ,  $\min(E_{cc}, E_{ic})$  and  $\min(E_{pc}, E_{ep})$ .

To expand the interval probability of government action and environmental pollution control of the enterprise,  $\alpha$  should be as large as possible, while  $\beta$  should be as small as possible. Therefore, there are some approaches: increase  $E_{pc}$ , reduce  $G_{sc} + G_{rc}$ , reduce  $R_t$  while increase  $R_t^*$  and increase  $\min(E_{cc}, E_{ic})$  while reduce  $\min(E_{pc}, E_{ep})$ .

In a short term, the game results shows that the supervision government should increase penalties for the excessive emission behavior of the manufacturing enterprise and decrease the making cost for environmental protection policy and the supervising cost for examination and evaluation. Besides, the payroll-tax deduction and exemption need to be carried out to motivate the enthusiasm of firm to forwardly control the pollution emission. Meanwhile, the manufacturing firm should increase the cost for pollution treating project and decrease the condemnatory cost and the payment for emission trading.

**3.2.2. Game between the Government and the Pollution Control Enterprise regarding Pollution Control in a Long Term.** The balance point between the pollution emitters and the government in a long term can be obtained according to the method mentioned above:

$$\alpha = 1 - [(G_{sc}+G_{rc}+G_{ic}) + (R_t - R_t^*)] / E_{pc} \quad (7)$$

$$\beta = \min(E_{cc}, E_{ic}) / [G_{ic} + \min(E_{pc}, E_{ep})] \quad (8)$$

The game results shows that the government should enhance the supervision and increase the payroll-tax cut but decrease the work cost for policy making, site investigation and assessment in a

long term. On the contrary, the government should increase the investment and penalties to stimulate the pollution emission enterprise and the third-party pollution control enterprise to forwardly treat pollution. Besides, the pollution emission enterprise should increase the control efficiency on environmental pollution and the pattern of professional third-party governance on environmental pollution is recommended.

In the long term game between the enterprise and the government, it can be indicated that it is a good choice to introduce the third party for pollution control. Therefore, the game relationship between the government and the third-party environmental pollution control enterprise is necessary to be considered over a long term, and the decision-making relationship between the government and pollution controllers is analyzed by establishing a complete information static game model. The following payment matrix can be obtained by analyzing the costs and benefits of the government and pollution controllers, as shown in the table below.

And then, the expected functions of the government and enterprises, and Nash equilibrium are obtained on the basis of compound decision game model, as follows:

$$\alpha = 1 - [(G_{sc} + G_{rc}) + (R_t - R_t^*)] / T_b \quad (9)$$

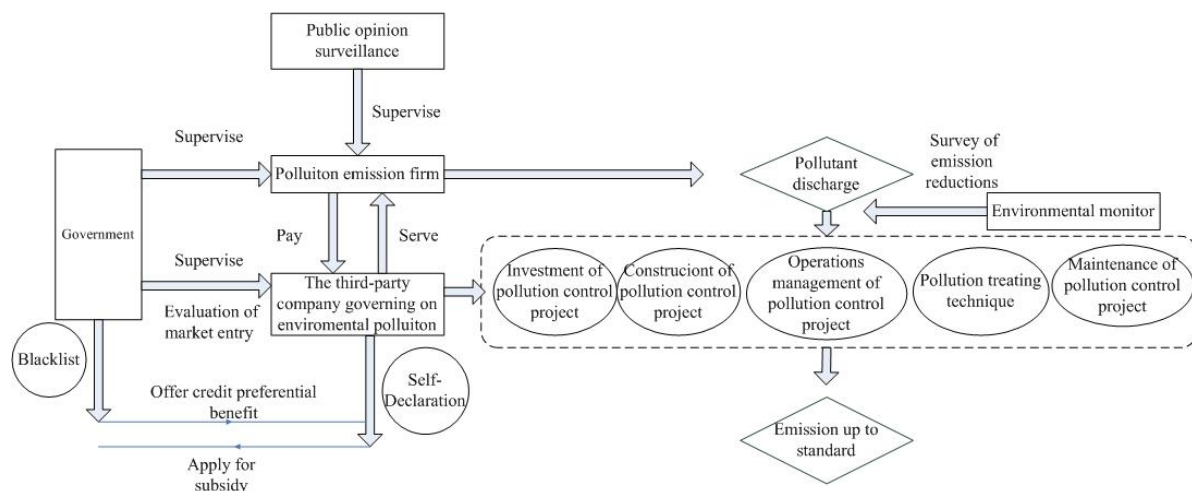
$$\beta = (T_{cc} - R_{mp} - R_{hr}) / [R_{pr} + \min(T_{pc}, T_b)] \quad (10)$$

By deriving the equilibrium solution of above equations, it concludes that the pollution emission enterprise should regulate the items of pollution control contract and increase penalties on the third-party company due to its poor control effects. The pollution control enterprise should increase the operating efficiency of the pollution treating project. Furthermore, the fourth-party assessment agent should be introduced to assess the pollution control performance. According to the evaluation, the government should set up a blacklist system to regularize the behavior of the third-party enterprise that offers environmental protection service. Besides, the bonus policies including green credit, tax preference, green bond and environmental protection fund need to be given for excellent pollution control enterprises.

It is also indicated in the research results that reasons for the difference of pollution control performance include the factors of fiscal tax reduction and exemption, input of pollution control fund, introduction of profession third-party governance, pollution control evaluation and granting of policy bonus. The multi-indicator evaluation system in this paper not only covers economic, technical, environmental protection and safety indicators for pollution control equipment in industrial sectors, but also accommodates the key points of the government's supervision over pollution control at macro level in order to comprehensively improve the long-term performance of the enterprises and government in industrial pollution control. It seems that relevant governmental authorities must take short-term measures as penalty when supervising the pollution control of enterprises. However, it is necessary to encourage and support the enterprises in terms of pollution control investment in a long term. Moreover, the introduction of the TGEP mode and establishment of assessment and evaluation mechanism is indispensable, and the policy support to the excellent enterprises and the blacklist system need to homogeneously given to promote the reward and punish at the same time for sustainable and efficient pollution control.

#### 4. Policy Suggestions for Third-party Governance over Environmental Pollution

The implementation of environmental protection facility evaluation system involves a lot of interested parties, including relevant administrative department, local management and quality control departments, evaluation organization, testing organization, manufacturers and so on. Relevant governmental organization authorizes the management organization and the evaluation organization to implement the environmental protection facility evaluation system and to assess the environmental protection equipments, respectively. Enterprises should submit the self-declaration information of products to the management organization for filing and accept the standardized supervision and inspection to the environmental marks of equipments organized by local management and quality control departments. The organization structure is shown in Fig. 3.



**Figure 3.** Organization Structure for the Third-party Governance over Environmental Pollution Mode

It is important to note that the responsibilities for pollution control of pollution emitters will in no case be transferred for the reason of introduction of the TGEP mode. In other words, pollution emitters should still take main responsibilities. Meanwhile, pollution emitters should also be responsible for the supervision and management with the third-party pollution control enterprise under the signed agreements. The third-party service company also needs to be responsible for the up-to-standard emission of the pollutants as agreed in the contract.

The administrative department of the government should prepare clear management system and detailed implementation rules for the execution of the TGEP mode to specify the rights and responsibilities of the entrusting party and the entrusted party. As for different fields involved in the third-party governance over environmental pollution, relevant technical specifications and working manuals need to be discussed and prepared to ensure the promotion of the TGEP mode. In addition, it is necessary to enact relevant environment service standards to quantify the environmental services and form measurable basis for payment, which is helpful to make “payment based on environmental effect” feasible and gradually perfect relevant processes and judgment standards for confirmation of legal responsibilities. For pollution emitters, professional organizations should be designated to supervise the whole process of generation, treatment and discharge of pollutants and approve the type and the quantity of pollutants. For pollution controllers, review mechanism needs to be established to assess pollution control capacities and supervisory mechanism can be set up to supervise whether the process and results of pollution treatment conform to the relevant environmental standards.

## 5. Conclusions

Comprehensive analysis method and site investigation are employed in this paper to build an evaluation index system by means of studying the environmental protection technology and standards. The system includes five subsystems that are further divided into 17 professional parameters derived from the performance of pollution control equipment operation, environmental protection,



technological economy, recourse consumption and manufacturing management. Furthermore, cost-benefit analysis is introduced to research on the investment and the return and a static game model is proposed to establish the decision condition and consequence by discussing the cost and benefit of the government, the pollution emission firm and the pollution control firm in a short time and in a long time, respectively. The game analysis aims to build effective evaluation mechanism to promote the application of the above evaluation index system.

The game results represent that the supervision government should increase penalties for the excessive emission behaviour of the manufacturing enterprise and decrease making cost for environmental protection policy and supervising cost for examination and evaluation in a short term. However, the government should pay attention to both the rewards and punishments in a long term. The fourth-party assessment agent should be introduced to assess the pollution control effects. According to the evaluation, the government should set up a blacklist system to regularize the behaviour of the third-party firm that offers environmental protection service. Besides, the bonus policies including green credit, tax preference, green bond and environmental protection fund need to be given for stimulating excellent pollution control firms

The pollution emission firm should increase the cost for pollution treating project in a short term, but the pattern of third-party governance on environmental pollution should be brought in to increase the pollution control efficiency and decrease the outlay cost in a long term. Furthermore, a normative pollution control service contract should be signed to restrain behaviors of the pollution control firm and share environmental protection benefits. Besides, the pollution control should increase the operating efficiency of the pollution treating project.

Based on this research, implementation mechanism is proposed to promote the efficiency of pollution control and regularize the environmental protection service offered by the third-party enterprise. Moreover, establishment of the evaluation index system for pollution control facility and evaluation mechanism for practice of the TGEP mode has guiding significance on leading environmental protection industry and promoting market-oriented development.

### Acknowledgements

The present work has been supported by the Major Research and Development Program of China (Grant No. 2016YFC0207901) and Central Basic Scientific Research Foundation of China.

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