Study on the Environmental Responsibility Measurement of Oil and Gas Resources Enterprises Based on Super Efficiency-DEA Model

Yanmei Sheng [1], Chunnan Liu[1*]

[1]*EnteNortheast Petroleum University, Daqing, Heilongjiang 163318, China*
**Corresponding author: Chunnan Liu. Email: 2466870118@qq.com*

ABSTRACT

With the rapid economic development, environmental pollution is getting worse. As heavily polluting enterprises, oil and gas resources enterprises, while playing an important role in national economy and the people's livelihood, must fulfill certain environmental responsibilities. On the basis of constructing the index system of environmental responsibility of oil and gas resources enterprises, the method of environmental responsibility measurement is put forward by using the super efficiency-DEA model, and obtaining the 2017-2021 Petroleum's input and output index data of the Nth oil field in Daqing, getting annual environmental responsibility value calculated in Lingo. The calculation results show that the environmental performance of the case of enterprises has reached the standard in the past five years, which shows that the relevant environmental measures taken by the enterprises have achieved certain results. However, due to the small value of implementation, it shows that the fulfillment of environmental responsibility does not reach the ideal state, being still a lot of room for improvement. In view of this, we put forward to strengthen the mechanism of environmental responsibility of oil and gas resources enterprises.

Keywords: *Oil and gas resources, environmental responsibility measurement, super efficiency-DEA, fulfillment mechanis.*

1. INTRODUCTION

Oil and gas resources play an important role in the world economic development and provide necessary resources support and energy security for all walks of life. However, they are typical high-pollution industries, consuming not only basic materials but also large amounts of gasoline, diesel, natural gas, clean water, electricity, chemicals and pharmaceuticals in the development of oil and gas resources. The use of these energy sources and chemicals generates a large amount of polluting gas, wastewater containing a certain amount of petroleum material, and a lot of solid wastes such as sludge and oil feet that are also generated from oil extraction and refining. The production of these waste gas, water and residue seriously pollutes the soil, vegetation, water and air around oil and gas resource development enterprises, affects the healthy growth of people and other living organisms, and the environmental crisis is aggravated.

In November 2013, the Third Plenary Session of the 18th Communist Party of China Central Committee made it clear that enterprises need to shoulder their social responsibilities and raise their social responsibilities to the international strategic level with a clear-cut stand. Since the first China Social Responsibility Report of Shell (China) Company was released in 1999, Stakeholders' demand for social responsibility information is getting stronger, which promotes enterprises to effectively fulfill their social responsibilities and releases their implementation status externally. By the end of 2021, the number of social responsibility reports released reached 1,926. Petro China Company Limited ("Petro China") started to release its social responsibility report in 2006 with reference to the third edition of the "Guide to Sustainability Reporting". As of 2021, it has released 16 consecutive years. Through the release of the social responsibility report, Petro China has strengthened the communication with stakeholders, increased awareness of social responsibility, and acted more forcefully in fulfilling social responsibility. The social responsibility report disclosed by Petro China

S. A. R. Khan et al. (Eds.): ICMSSE 2022, AHCS 12, pp. 336–342, 2023.
https://doi.org/10.2991/978-94-6463-056-5_48

includes three major parts: economic responsibility, environmental responsibility and social responsibility. And the importance of environmental responsibility is increasing day by day, which makes the measurement of environmental responsibility fulfillment a very important research topic. In this paper, an oil and gas resource enterprise affiliated to Petro China is taken as a case study. By summarizing the research results in this field at home and abroad, the index system of environmental responsibility input and output is constructed with reference to the ecological benefits index proposed by the World Business Council for Sustainable Development (WBCSD). Meanwhile, the super efficient-DEA model is introduced to measure the implementation of the case enterprises' environmental responsibility from 2017 to 2021 and the fulfillment mechanism of the environmental responsibility of oil and gas resources enterprises is put forward according to the measurement results.

2. LITERATURE REVIEW

Among the research results on environmental responsibility, the research directions of scholars mainly focus on four aspects: environmental responsibility management, environmental information disclosure, environmental performance evaluation and environmental responsibility fulfillment mechanism. But the qualitative research on environmental responsibility measurement is basically in the exploration stage and the literature is relatively small. Carroll (1979) first proposed a social responsibility model that incorporates corporate environmental responsibility into the model for measurement [1]. Lenzen et al. (2007) studied the environmental responsibility and its measurement methods of enterprises' production and consumption [2]. T. Sun (2014) constructed an environmental responsibility measurement model of enterprise pollutant discharge by combining the shadow price method with the input-output method [3] and used this model to measure the environmental responsibility of Jiangsu MW Group Co., Ltd pollutant discharge, verify the validity of the measurement model and enrich qualitative research on the theory of enterprise environmental responsibility measurement. X. Y. Han (2018) fully considered the actual situation of energy consumption and pollutant emission enterprises, and used the revised input-output model to measure the environmental governance responsibility and environmental improvement responsibility of the energy consumption and pollution discharge of the enterprise, and the research results verified the effectiveness of the revised model [4]. F. He (2020) combined the SBM model with undesired outputs and the "super-efficiency" model to form an SBM super-efficiency model with undesired outputs, and explored the impact of corporate environmental responsibility performance on corporate economic benefits [5].

3. CONSTRUCTION OF ENVIRONMENTAL RESPONSIBILITY MEASUREMENT MODEL

In 1978, A. Charnes and W. W. Cooper, the famous American operations research scientists, proposed the Data Envelopment Analysis (DEA). It is a linear programming analysis method, through controlling the decision-making unit (DMU), to effectively evaluate the relative efficiency of similar economies with multi-index input and output. Since its introduction, DEA has been widely used in different disciplines, prompting scholars to constantly make improvement and innovation of the traditional DEA model. Since the traditional DEA model can only determine the validity of the DMU rather than distinguish the differences between effective DMU, Andersen and Petersen proposed the super efficiency-DEA in 1993 to achieve a reasonable ranking of DMU efficiency and to further distinguish the pros and cons of the effective DMU. Due to the limited achievements of the qualitative research on the measurement of environmental responsibility of oil and gas resources enterprises at present, and the difficulty of obtaining input and output index data, especially the environmental data began to be monitored only in recent years, it is impossible to conduct large sample comparison. Instead, taking each year of the case enterprise as DMU, a longitudinal comparison of the fulfillment of environmental responsibilities in different years can be carried out based on the measured results and an effective fulfillment mechanism can be put forward accordingly. The super efficiency-DEA model is as follows:

$$\begin{cases} \min\left[\theta^* - \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)\right] \\ \sum_{\substack{j=1 \\ j\neq j_0}}^{n} \lambda_j x_{ij} + s_i^- = \theta^* x_0 \\ \sum_{\substack{j=1 \\ j\neq j_0}}^{n} \lambda_j y_{ij} - s_r^+ = y_0 \\ \lambda_j > 0, j = 1,2,\ldots,n \\ s^+ \geq 0, s^- \geq 0 \\ r \in \{1,2,\ldots s\}, i \in \{1,2,\ldots m\} \end{cases}$$

ε is Archimedes Infinitesimal. The above model can be used to solve θ^* , and θ^* represents the super efficiency value of DMU.

4. RESEARCH DESIGN

4.1 Design of Index System for Environmental Responsibility Measurement of Oil and Gas Resources Enterprises

When the super efficiency-DEA is used to measure the fulfillment of environmental responsibility of oil and gas resources enterprises, it is particularly important to

choose the appropriate input and output indices. In this paper, with reference to the ecological benefits index proposed by WBCSD, the input and output index system of environmental responsibility is constructed to ensure that the effectiveness of DMU can be adequately measured. The specific index system is shown in table 1.

Table 1 Index system for environmental responsibility measurement of oil and gas resources enterprises

Index category	Index name	Index composition
Input indices	Raw materials	The amount of various materials
	Energy	Electricity Gasoline and diesel oil Natural gas Other fuels
	Water resources	Annual consumption of water
	Environmental protection funds	Sewage disposal expense Exhaust fumes emissions expense Land (sea area) use and loss compensation expense Safety production expense Environmental safety risks' management expense
Output indices	Gas output	Sulfur dioxide (SO2) emissions Nitrogen oxide (NOx) emissions Smoke and dust emissions
	Water output	Chemical oxygen demand(COD) Wastewater discharge
	Solid waste output	Sludge and oil feet from oil extraction and refining

4.1.1 Input Index Set

In setting the input index system, it mainly involves the input of routine materials, the consumption of energy and water resources, and the environmental protection funds paid by oil and gas resource enterprises.

(1) Raw materials input. In the development of oil and gas resources, it needs to consume a variety of raw materials, including tubing, sucker rods, sucker pumps, down hole tools, paint, insulation materials, well materials, fire safety equipment and other materials.

(2) Energy. To measure the fulfillment of environmental responsibilities, energy consumption is a very important index. The energy consumed in the development of oil and gas resources mainly includes electricity, gasoline, natural gas and other fuels.

(3) Water resources. During the exploitation of oil and gas resources, water injection into the formation is required in order to maintain reservoir pressure and increase oil recovery. The consumption of a large amount of freshwater resources has made water flooding costs one of the larger projects in the costs of oil and gas exploration.

(4) Environmental protection funds. In order to strengthen environmental protection, oil and gas resources enterprises regularly invest in environmental protection funds. Specific projects include: ①Sewage disposal expense. The water company will charge the same amount of sewage disposal expense according to the amount of water purchased per month. ②Exhaust fumes emissions expense. According to the 13th provision "Regulations on the collection, use and management of pollutant discharge expense", the Daqing City Environmental Protection Agency regularly released the amount of pollutant discharge expense per quarter of major companies via the Daqing City Environmental Information Network. The index calculation is to aggregate the data of the four quarters to derive the annual total amount of exhaust fumes emissions expense. ③ Land (sea area) use and loss compensation expense. It is a kind of compensation expense after the oil and water wells destroy the surrounding land. ④Safety production expense.

4.1.2 Output Index Set

When DEA models are applied to the general field, the conventional idea is to obtain the maximum output with the least investment. The majority of the output refers to the expected output. However, in measuring the

fulfillment of environmental responsibility of oil and gas resources, the focus is mainly on the emission of environmental pollutants, which is a typical non-expected output. Therefore, the output index system of this paper is set for the output of gas, water and solid waste.

(1) Gas output. During the process of oil and gas resource extraction, gathering and transportation, a considerable amount of oilfield associated gas will be produced. At the same time, the use of necessary equipment such as various boilers and furnaces emit a large amount of pollutant gases such as smoke and dust and generally contain sulfur dioxide (SO2), carbon dioxide (CO2), carbon monoxide (CO), ammonia nitrogen compounds (NH3-N) and other harmful gases, which can directly endanger the atmosphere.

(2) Water output. With the consumption of a large amount of freshwater resources in the exploitation of oil and gas resources, a lot of waste water will be produced. The composition of waste water is very complicated and generally contains a certain amount of petroleum substances, ammonia nitrogen and chemical requirements, which will inevitably cause the pollution of groundwater around the wellsite and directly affect the growth of surface organisms.

(3) Solid waste output. In the exploitation of oil and gas resources, there will be a large number of oily sludge with extremely complex composition. The petroleum sludge has been listed in the national list of hazardous wastes in China, such as sludge and oil feet produced from oil extraction and refining [No. 071-001-08] and sludge produced from the refining of petroleum products [No. 251- (001-012) -08)] [6], which need to be treated harmlessly, otherwise it will cause great pollution. Moreover, the sludge contains a certain amount of crude oil, which needs to be treated as a resource to enhance the value of resources recovery and utilization.

4.2 Case Analysis - Taking the Nth Production Plant in Daqing Oilfield as an Example

The Nth Oil Production Plant, part of Daqing Oilfield, has been in existence for 36 years since it was incorporated in Daqing Trade and Industry Bureau in 1986. As of the end of December 2016, the Nth Oil Production Plant has cumulatively produced 302 million tons of crude oil and 42.8725 million tons of recoverable reserves. In recent years, the development situation of oil extraction plant continued to improve, surpassing the tasks of crude oil and natural gas production. By optimizing the structure of injection and production, the formation pressure was restored steadily, the water flooding and aquifer control was effectively controlled and the natural decline rate was controlled at about 7% for 6 consecutive years.

4.2.1 Data Source for Measurement Index System

Most of the input and output index data were obtained by referring to related data, such as the internal financial statements of the oil production plant, the monthly reports of environmental statistics, the environment statistics yearbooks of the city and the social responsibility reports or the sustainability reports of China National Petroleum Corporation (CNPC). In addition, due to the incompleteness of individual environmental monitoring projects, some of the data cannot be obtained. The specific input and output index data is as shown as in table 2.

Table 2 Input and output index data sheet of the Nth oil production plant from 2017 to 2021

Index categories	Index name	Index composition	2017	2018	2019	2020	2021
Input indices (unit: ten thousand yuan)	Raw materials	The amount of various materials	56237.20	53216.08	55068.53	48347.84	43946.02
	Energy	Electricity	4989.40	4599.58	4824.61	3657.75	3386.12
		Gasoline and diesel oil	3417.90	2600.62	2320.80	3314.20	3370
		Natural gas	67896.25	73952.22	68545.75	76512.31	83065.80
		Other fuels	7.66	6.60	6.84	9.03	8.08
	Water resources	Annual consumption of water	6988.42	8900.78	7988.60	9623.73	9331.73
	Environmental protection funds	Sewage disposal expense	2084.13	2084.17	2073.06	2078.46	2017.65
		Exhaust fumes emissions expense	93.75	74.27	73.79	66.85	39.64

		Land (sea area) use and loss compensation expense	1733.87	1770.38	1796.72	1056.19	724.10
		Safety production expense	4494.27	3806.80	3943.72	3007.87	3218.86
		Environmental safety risks' management expense	1.95	1.86	1.82	0.87	1.30
Output indices (unit: tons)	Gas output	SO2 emissions	38.45	41.78	39.86	48.05	75.29
		NOx emissions	113.26	123.95	117.68	142.57	223.39
		Smoke and dust emissions	15.89	18.96	17.54	21.81	34.17
	Water output	COD	16927	17663	17358	18609.5	18848.2
		Wastewater discharge	51926710	52264880	54253640	53222000	57864600
	Solid waste output	Sludge and oil feet from oil extraction and refining	15823	10500	16764	18500	14678.59

Data source: the Nth oil production plant environmental statistics monthly, Daqing environmental statistical yearbook and CNPC social responsibility reports.

4.2.2 Measurement Results Analysis

This paper uses the super efficiency-DEA model to measure the fulfillment of the environmental responsibility of the plant, writes the program with Lingo language [7] to achieve the automation of the calculation process and DMU efficient sorting and finally runs the operation of this program to obtain the relatively accurate measurement results. The measurement results of each DMU are shown in table 3.

The fulfillment of environmental responsibility in 2017-2021 is shown in Table 3, and the measurement results in the past five years are all greater than 1, indicating that DMU is in an effective state. The measured results of 2020-2021 have slightly risen compared with that of 2018, and the growth trend shows that the environmental protection measures taken by the enterprise have been effectively implemented and the fulfillment of environmental responsibility has been somewhat improved. The Nth Oil Production Plant actively has assumed environmental responsibility and invested in the construction of Nan District Urban Domestic Sewage Treatment Plant with a total processing capacity of 30,000 cubic meters per day and about 11 million cubic meters of domestic sewage annually. In order to improve the quality of regional water environment, the Green Lake containing domestic sewage near the oil production plant has been transformed into a beautiful ecological lake to accumulate a wealth of water resources for the growth of vegetation. In the process of implementing the national pollution abatement policy, Xingnan Boiler House has implemented a coal-to-gas project to reduce annual coal consumption by 11,800 tons, 45 tons of soot and 58 tons of sulfur dioxide. In order to take an active part in the activities of oil field companies to launch "less drop of water, less drop of oil and build green oil field", the oily sludge disposal equipment developed by The Nth Oil Production Plant and Huayou Huibopu Technology Co., Ltd had been successfully applied in 2015 to achieve all the decontamination and recycling of waste mud and enormously boost the enthusiasm of other oil production plants on the construction of oily sludge disposal stations. At present, Daqing Oilfield has built 6 oily sludge disposal stations with an annual processing capacity of 700,000 cubic meters and 15 oily sludge pools with an annual processing capacity of 250,000 cubic meters. Daqing Oilfield was named "Environment-friendly Enterprise" by the Environmental Protection Department of Heilongjiang Province.

Table 3 Measurement results

Year	2017	2018	2019	2020	2021
Measurement Results	1.2013	1.0883	1.1206	1.6589	1.6865

5. FULFILLMENT MECHANISM OF ENVIRONMENTAL RESPONSIBILITY OF OIL AND GAS RESOURCES ENTERPRISE

Although the scores of the measurement results in each year are all greater than 1 in Table 3, the overall score is low, indicating that there is still much room for improvement in the fulfillment of environmental responsibility. Further measures need to be taken to reduce pollutant discharge and enhance the sense of environmental responsibility fulfillment. The measures to be taken include the following three items.

5.1 Create Environment-friendly Corporate Culture

Oil and gas resources enterprises should pursue the corporate culture of "contributing to energy and creating harmony" proposed by Petro China to create clean, green, economical, safe and sustainable enterprises and make full use of the two resources and two markets to ensure the national energy security and guarantee stable supply of oil and gas market, providing society with high quality, safe and clean oil and gas products and services, establishing a resource-saving and environment-friendly enterprise to create harmony between energy and the environment, fulfilling environmental responsibilities and creating harmonious development between enterprises and the environment. Under the influence of corporate culture, each employee incorporates the concept of environmental protection into their work, and the awareness of environmental responsibility fulfillment is obviously enhanced.

5.2 Deepen the HSE System Construction

Oil and gas resources enterprises attach great importance to the Health, Safety and Environment (HSE) work, implement the environmental responsibility system and the safety-production performance assessment. According to "Quantitative Examination and Assessment Standards of HSE Management System" formulated by Petro China, enterprises should employ audit experts to carry out HSE system, which audit not only the leadership performance and process control but also the critical work sites, and endeavor to enhance HSE management performance. Enterprises should further develop the grass-roots HSE standardization, construct the grass-roots HSE training matrix of the high-risk main profession and prepare matrix application manual to achieve standardization of post operation, work sites and equipment management and ultimately ensure that all risks are under control.

5.3 Strengthen Environmental Risk Management

According to "Administration Measures of China Petroleum Environmental Incidents" and "Regulations on Prevention and Control of Environmental Risks of Petroleum Pipeline in China" formulated by Petro China in 2016, enterprises' environmental risks need to be classified management, namely oil and gas leakage pollution, excessive discharge of pollutants and uncontrolled radioactive sources, the destruction of biological diversity, environmental violations and secondary pollution of safety accidents and other six categories. And the following specific measures can be used to strengthen environmental risk management to ensure its full control: to move the starting point of environmental risk management forward, to establish and improve a risk management mechanism of "stratified management and hierarchical control", to perform management and control measures step by step, to strengthen the management of unexpected environmental incidents, to control, mitigate and eliminate the hazards of environmental incidents.

6. CONCLUSION

Through the research, the super efficiency-DEA model can measure the fulfillment of environmental responsibility of oil and gas resources enterprises, and convert purely qualitative research on the environmental responsibility fulfillment of oil and gas resources enterprises into quantitative research in the theoretical circle, and achieve new breakthroughs in the application field of DEA. According to the results, the heavy polluting enterprises have formulated the environmental responsibility fulfillment mechanism in a targeted manner and made their own efforts to further fulfill the environmental responsibility, enhance the sense of social responsibility and build a harmonious society.

ACKNOWLEDGEMENT

Funding: Heilongjiang Province Philosophy and Social Science Research Planning Project "Study on the Environmental Responsibility Measurement and Dynamic Mechanism of Energy Enterprises in Heilongjiang Province" (Project No. 20GLB121).

REFERENCES

[1] A.B. Carroll, A Three-dimensional conceptual model of corporate social performance, The Academy of Management Review, vol.4, no.4, 1979, pp. 497-505.

[2] M. Lenzena; J. Murraya;F.Sackb and T. Wiedmannc, Shared producer and consumer responsibility, Ecological Economics, vol. 61, no.1, 2007, pp. 27-42.

[3] T. Sun and T. Y. Zhao, The Environmental responsibility measurement of enterprise sewage and its application, China Population Resources and Environment, vol.24, no.5, 2014, pp. 102-108.

[4] X. Y. Han, T. Y. Zhao and T. Sun, Research on environmental responsibility measurement of enterprise energy consumption and pollution discharge from the perspective of virtual value, Research on Generalized Virtual Economy, vol.9, no.4, 2018, pp. 59-66.

[5] F. He, R. Liu and L. L. Chen, Will fulfilling environmental responsibilities improve the economic efficiency of enterprises? - Based on a stakeholder perspective, Journal of Beijing Institute of Technology, vol.22, no.6, 2020, pp.32-42.

[6] Ministry of Environmental Protection of the People's Republic of China, National hazardous waste directory, August, 2016.

[7] J. H. Hu, Super efficiency-DEA model and its implementation in lingo, Jiangxi Electric Power Vocational & Technical College, vol.28, no.4, 2015, pp. 58-62.