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Economic and Environmental Evaluation of Using Low-Medium Temperature Geothermal Energy in Northern China

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ABSTRACT

Geothermal and other renewable energy resources are becoming attractive solutions for clean and sustainable energy needs of China. There are rich geothermal resources in China which have been proven equivalent to 8.6×10^{15} tons of coal. However, the main way of utilizing geothermal energy is district heating in some big cities in north China. The utilizing scale is quite small and still has certain gap with the size of the market. The main purpose of this study is to investigate the potential of geothermal energy market in China including calculation of economic efficiency and the environmental impact on northern China.

Based on the characteristics of low temperature geothermal resources, we built a comprehensive evaluation system. First, we set up a file to do basic financial evaluation of geothermal engineering operational data for Xianyang, Xiongxian and Tianjin; second, we used super-efficient DEA model to evaluate the economic efficiency in northern China from the large regional perspective; Then, we used LCA method to calculate the environmental impact potentials during geothermal development process; Catastrophe progression method was finally used to integrate economic and environmental indicators objectively and systematically, which can be used to predict the potential of the geothermal energy market in China.

The results show that (i) The geothermal heating project is economically viable in northern China. Economic analysis suggested that average payback period is from four to eight years. Compared to the heat pump, hydrothermal geothermal resources is more efficient; (ii) Geothermal energy contributes a lot to greenhouse gas reduction target, although about 95.98% of total environmental impact occurs in the construction period; (iii) All the efficiency index is more than 0.8, which means there is a huge potential of geothermal energy market in China.

1. INTRODUCTION

The last few years have seen a rapid development of geothermal energy, which is being used for heating, in the northern cities of China. The usage of geothermal heating can help reduce a large amount of emissions of harmful substances, avoid air pollution, and can replace the conventional energy effectively. In recent years, there is a large increase in China's utilization of low temperature geothermal energy heating, which is mainly in form of the traditional hot water type geothermal heating. The average annual growth rate is 23%. The total geothermal heating area in China is nearly 20 million square meters, among which Tianjin took up 9.4 million square meters (Zhao X.G., Wan,G., 2014). In Tianjin, the geothermal heating area accounts for 15% of the whole heating area.

However, due to different sizes and resource endowments of different cities, the level of geothermal heating is inevitably uneven in China's northern towns. Ma Jianzhong compared the geothermal heating and gas program of a certain district in Beijing, and he drew a conclusion that geothermal heating is economically feasible from the perspective of investment and operation costs (Ma, J.Z., 2007). Chen Shaoling obtains that immature design of geothermal heating project will decrease the effect of energy saving (Chen, S.L., 2009). Zhu Jialing and Zhang Fengshan also believe that geothermal heating need to further improve its energy saving potential (Zhu, J.L., Zhang, F.S., 2000). Lin Li and other researchers conducted comprehensive analysis in the development and utilization conditions of geothermal resources in Tianjin, and they pointed out that we must take the road of sustainable recharge development (Ma, F.R., Lin, L et al, 2006). Most existing research focus on the study of geothermal heating cases of each city and the project's impact on the environment, while there're few studies based on macroeconomic and management perspective.

This paper mainly focuses on the perspective of management. We studied the potential of geothermal heating market in northern China. Based on detailed carding of regional features of low-temperature geothermal resources in northern cities, we selected three typical cities as our study objects, including Xianyang, Xiongxian, and Tianjin City, in order to quantify and compare the economic efficiency and environmental impact of other geothermal heating projects. Finally, using a comprehensive evaluation system in combination with earlier evaluation results, comprehensive index are given to predict market potential of northern China's geothermal energy development.

First, the potential of geothermal resources and its development condition in northern China are presented. And to make analysis more specific, three typical cities are selected. Next, the economic and environmental impact of hydrothermal geothermal heating projects will be respectively evaluated, and comprehensive centralized comparison will be given. Finally, with the dimensionless index, the comprehensive development potential of geothermal heating in these three cities are measured, leading to a reasonable prediction of potential of development and utilization of geothermal energy in typical urban areas of northern China, based on which reasonable proposals of promoting long-term planning and usage of geothermal energy in northern regions are given from a macroeconomic and management perspective.

2. THE STATUS QUO OF GEOTHERMAL ENERGY DEVELOPMENT IN NORTHERN CHINA

2.1 Geothermal resources situation in northern China

China is rich in geothermal resources, which has been proven equivalent to 860 trillion tce and has regional distribution traits obviously. The main sedimentary basin (plain) in China is about $2.5x10^{22}$J geothermal resource reserves, which is equivalent to 853.19 billion tons of standard coal (Pan, X.P., and Zheng, K.Y., 2009). However, most basins contain low-medium temperature geothermal resources and 60% of them are located in northern China (Fig.1).

On the characteristics of geothermal resources among the cities, Xianyang is rich in geothermal resources with the notable features of high temperature, high pressure, abundance water and excellent quality. Xiongxian's geothermal resource is pretty good in quality to achieve "national medical hot mineral water standards". The high temperature water can also be widely used for heating, bathing, nursing, breeding etc. Geothermal reservoirs in Tianjin belong to conductivity geothermal resources, which is widely distributed in muti-reservoir structure and has big potential in using (Li, J.F., Sun, B.C. et al, 2005).

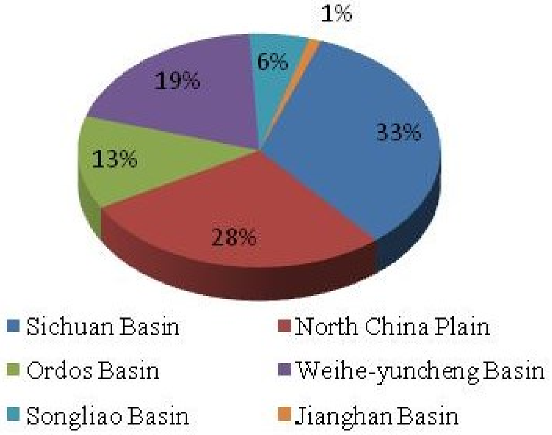

Figure 1: Main plains (basins) geothermal resource distribution in China

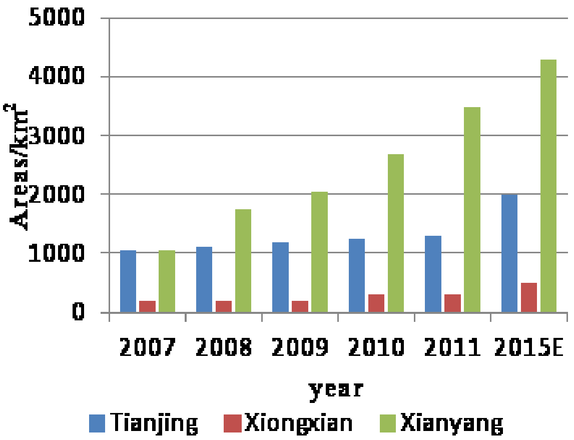

Figure 2: Geothermal heating area of major cities in northern China

2.2 Geothermal resources utilization in northern China

Currently, geothermal heating is the major way of developing and utilizing the low temperature geothermal energy in northern China. Geothermal heating market is beginning to take shape in typical northern cities, including Shenyang, Beijing, Tianjin, Xianyang, Xi'an and Xiongxian. From 2007 to 2010, geothermal heating proportions of the total area have been rapidly growing (Fig.2) and the technology of hydrothermal geothermal heating got more mature. By the end of 2010, Xianyang and Xiongxian have achieved heating area of about 3 million square meters and 1 million square meters, accounting 25% and 97% for the local heating market respectively. Tianjin has 424 geothermal wells and produces 32.5 million cubic meters each year. In the demand market, about 15.5 million cubic meters is used for geothermal heating in residential areas in Tianjing, which accounts for 66.7% of the total area of exploitation.

3. METHODICAL APPROACH

3.1 Basic Evaluation Model

3.1.1 Economic Evaluation Model

Technical-economic indicator is a relatively mature method among the theories to evaluate investment projects and also the most widely used as evaluation basis. According to Methods and Parameters of Construction Project's Economic Evaluation (the Third Edition) promulgated by China National Development and Reform Commission and the Ministry of Construction in July 2006, we mainly selected the following indicators:

$$NPV = \sum_{t=0}^{n} (CI - CO)_t (1 + i_c)^{-t} \quad (1)$$

$$\sum_{t=0}^{n} (CI - CO)_t (1 + IRR)^{-t} = 0 \quad (2)$$

$$\sum_{t=0}^{P_t} (CI - CO)_t (1 + i_c)^{-t} = 0 \quad (3)$$

$$ROI = \frac{EBIT}{TI} \times 100\% \quad (4)$$

where NPV is net present value, n is the period of the project, CI is cash inflows and CO is cash outflows. $(CI-CO)_t$ is the net cash flow in the t year, i_c is a benchmark discount rate, IRR is the internal rate of return, P_t is the dynamic payback period, ROI is the total investment yield, TI is the total investment for the project, and EBIT equals to the annual average of earnings before interest and tax.

NPV mainly investigates the profitability of geothermal heating project in given period by calculating the discounted cash flow. Financial internal rate of return assumes that NPV is zero and is compared to the benchmark yield of geothermal heating industry. So we can get the profit level of the project. Dynamic payback period considers the time value of money and reflects the payback period of the project. Total investment yield is the most direct expression of the amount of net earning annually created by geothermal projects.

We selected super efficiency Data Envelopment Analysis model (super efficiency DEA) based on the calculation results of technical-economic indicators. Using the model, we accounted the input-output level of geothermal heating project during a continuous period in the urban area of northern China. Also, it provides a regional perspective to compare geothermal used in northern China. The model can be expressed as follows:

$$Min\theta$$
$$s.t.\begin{cases}\sum_{\substack{i=1\\j\neq i}}^{n} X_j\lambda_j + S^- = \theta X_o\\ \sum_{\substack{i=1\\j\neq i}}^{n} Y_j\lambda_j - S^+ = Y_o\\ \lambda_j \geq 0,\ j = 1,2,\ldots,k-1,k,\ldots,n\\ S^- \geq 0,\ S^+ \geq 0\end{cases} \quad (5)$$

where θ is the efficiency value of unit decision, x and y are the input and output variables. λ represents the combination ratio of effective decision-making unit where Σλ＞1, Σλ=1 or Σλ＜1 respectively show that economies of scale is diminishing, constant or incremental. s^- and s^+ are slack variables, which represent the input and output deficiency excess.

3.1.2 Environmental Impact Assessment Model.

We used the life cycle assessment (LCA) method, which reflects the idea of "cradle" to "grave". Also, it combines the quantitative and qualitative analysis to consider the impact on the environment of entire life cycle process of geothermal heating project. On the one hand, we analyzed the environmental benefits of geothermal energy compared with conventional energy; on the other hand, we compared environmental effects from diverse construction programs of geothermal heating scheme.

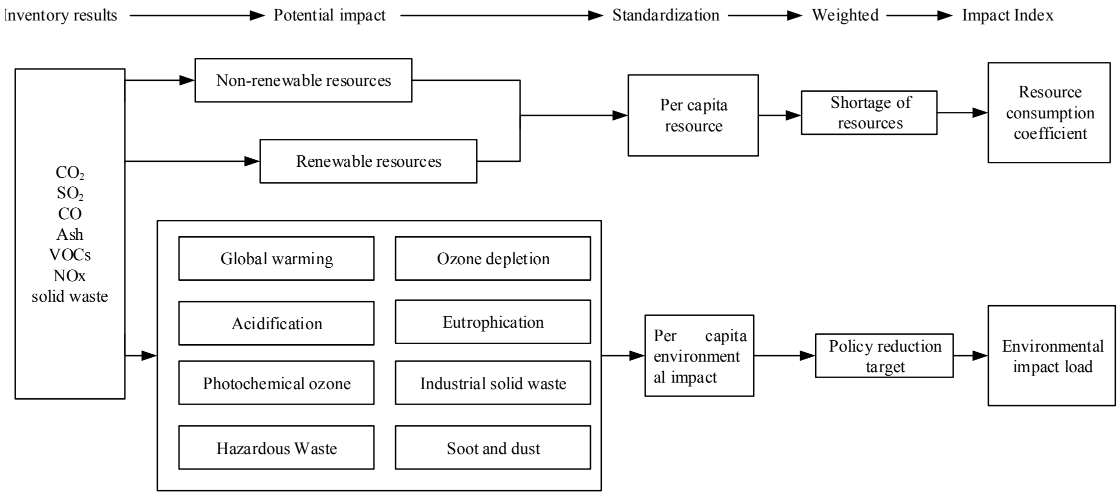

Figure 3: LCA model frame

According to ISO 14040 standard framework, we built life cycle assessment modeling framework (Fig.3) Through the assessment of contribution to change environment, we tried to explain some inventory data, which can be calculated by the following steps: calculating environmental impact potential, standardizing data, conducting weighted assessment and calculating environmental impact loads (Pehnt, M, 2006).

$$\mathrm{EP(n)} = \sum EP(n)m = \sum[Q(n)mEF(n)\,m] \quad (6)$$

In Eq.6, EP(n) is the potential environmental impacts value of n; m is a kind of emission. Q(n)m is the emission load of material m. EF(n)m is equivalency factor of the emission m.

To fit the current environmental situation in China, we used the eBalance software developed by China Yike Environmental Ltd to conduct data classification analysis.

3.2 Comprehensive Evaluation System

We use the catastrophe progression method to have sequencing analysis in the comprehensive benefits of geothermal heating projects, which makes the economic and environmental evaluation results comparable. The principle used as shown in table 1:

Table 1: Primary mutation model of potential function

Type	Potential function $f(x)$	Divergence equation	Schematic diagram
Swallowtail catastrophe	$1/5X^5 + 1/3aX^3 + 1/2bX^2 + cX$	$a = -6X^2, b = 8X^3, c = -3X^4$	$\overbrace{a \quad b \quad c}$
Butterfly mutations	$1/6X^6 + 1/4aX^4 + 1/3bX^3 + 1/2cX^2 + dX$	$a = -10X^2, b = 20X^3, c = -15X^4, d = 4X^5$	$\overbrace{a \quad b \quad c \quad d}$

Where X is State variables of the system; a, b, c, d are control variables. The control variables' significance ranks are decided by the internal mechanism of catastrophe model. (table.2)

The designed comprehensive benefit evaluation system strictly abides the principle of the catastrophe progression model. It examines and weighs geothermal energy development and utilization potential in northern China from prospects of economics, environment and resources.

Table 2: Geothermal heating project comprehensive evaluation system

	Second class indicators	Third class indicators
Geothermal heating project comprehens-ive evaluation system A	Economic indicators B_1	Net Present Value（ten thousand yuan）C_1
		Internal Rate of Return（%）C_2
		Return on Investment （%）C_3
		Payback period（year）C_4
	Environmental indicators B_2	Energy saving costs（ten thousand yuan）C_5
		Annual CDM income（ten thousand yuan）C_6
		The average annual cost rate of emission reduction（ten thousand yuan）C_7
		Total gas emission（ten thousand tons）C_8
	Energy saving indicators B_3	Annual coal consumption savings（ten thousand tons）C_9
		Energy conservation and emissions reduction rate of investment （%）C_{10}
		Unit of industrial added value and savings（tons/ ten thousand yuan）C_{11}
		Unit of the added value of industrial water consumption（m^3/ ten thousand yuan）C_{12}

3.3 Data Sources

According to the degree of resource utilization in eastern, central and western regions of northern China, we selected Tianjin, Xiongxian and Xianyang as representatives of target area.

The data of geothermal resources and the distribution is from the statistics offered by China Geological Survey Bureau (2006).The data of geothermal heating area is taken from the China Urban Construction Statistics Yearbook (2010); investments and earnings of geothermal heating projects are taken from our investigation. Benchmark interest rate is taken from the China Financial Yearbook (2002-2012); environmental impact loads are calculated based on the comprehensive energy reduction indicators from Twelfth Five-Year Plan (ECER-125).

4. THE RESULT AND ANALYSIS

4.1 Economic evaluation and analysis

The northern Chinese cities often have big scale and relatively concentrated residential building distribution. Geothermal heating is mostly operated as regional central heating project, leading to the economies of scale of the geothermal resources. The low temperature geothermal energy developments in northern area are mainly in the form of hydrothermal heating, which has a long history of development and relatively mature technology. As shown in table 3, all heating projects' net present value are greater than zero, the internal rate of return are greater than the benchmark yield, and the average Payback Period are 5 years or so. Therefore it is illustrated that the geothermal heating project in each city are in good financial performance, and that providing geothermal energy heating to northern area is economically feasible in theory.

Table 3: Economic parameters analysis of geothermal heating system in typical northern cities

Area	Payback Period	NVP	IRR	The main factors that influence the sensitivity
Xiongxian	4.35	2438.72	16.08%	Investment, income, operating costs, heating area
Xianyang	5.12	520.0	14.5%	
Tianjin	5.06	433.62	22%	

In order to reflect the relationship between the characteristics of geothermal resources in northern China and the degree of development and utilization more intuitively, the financial internal rate of return is selected as a sensitivity analysis indicator in this article. And three factors, investment, income, and operating costs, are increased and decreased by 5% respectively. Therefore, the influences on geothermal heating project can be observed.

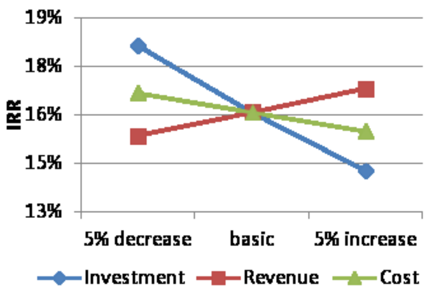

Figure 4a: sensitive analysis of Xiongxian

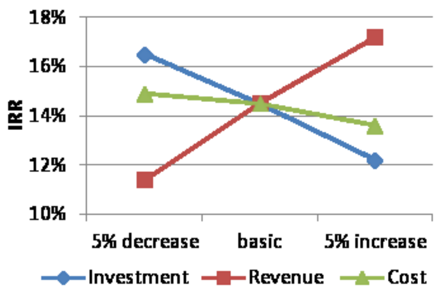

Figure 4b: sensitive analysis of Xianyang

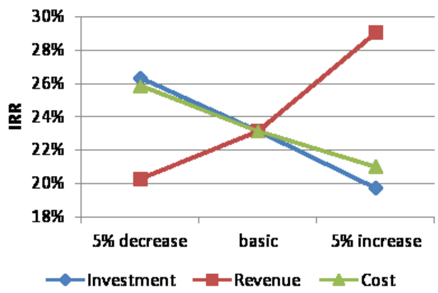

Figure 4c：sensitive analysis of Tianjin

Figure 4： Sensitive analysis of typical cities in northern China

Xiongxian is known as China's geothermal city. Thanks to its superior local resources conditions and scientific overall planning, it has a stable project investment income and the internal rate of return range is less than 2%, which indicates a strong anti-risk ability of the geothermal development and utilization.

Xianyang is one of the earliest city in China in terms of development and utilization of geothermal resources. However, the resource injection barrier has been a regional geothermal energy development bottleneck. As a result, there is a high sensitivity to the regional geothermal project and a weaker anti-risk ability of the geothermal development and utilization in that area.

Under the impetus of production mechanism, Tianjin got a rapid development in geothermal industry. Compared to Xiongxian and Xianyang, it has a higher internal income compensation, which indicates that Chinese government plays an important role in the process of promoting geothermal energy development and utilization. At the same time, the most sensitive factor of heating projects in Tianjin is income, thus strict control of cost in the process of development and utilization is required. However, as fossil fuels being increasingly tense, heating prices is having bigger upside. Therefore, geothermal heating in Tianjin has tremendous market potential.

Based on financial indicators and the results of the analysis, the super efficiency DEA model and operation results built in this article are shown below in table 4.

Table 4: Super efficiency value and the ranking of geothermal heating project in typical cities in north China

Area	Super efficiency value	Ranking
Xiongxian	255.55%	1
Xianyang	176.34%	2
Tianjin	137.89%	3

All input - output DMU unit of three geothermal heating projects in typical cities in north China are proved efficient, which indicates that the geothermal projects have realized smallest input and largest optimizing production output. The super efficiency in Xiongxian is of highest value, which reached 255.55%, showing that its economic benefits are very significant. Xianyang has a long history of development, a relatively mature geothermal heating operation mode, and a stable input-production rate. But its technical input - output efficiency is slightly lower than Xiongxian, limited by traditional technology and resource constraints.

Financial analysis results show that the geothermal project in Tianjin got strong support from local government, hence the capital input - output efficiency is slightly lower than that of Xianyang when government investments are included.

By ranking super efficiency value, the model results were found to fully confirm that the geothermal development project has the characteristics of long-term and stable returns. From the long-term development perspective, located in a high latitude area, China's northern cities' heating market has great potential. And improving the utilization efficiency of investment is the next target.

4.2 Environmental evaluation and analysis

In the whole life cycle of geothermal engineering process, there are mainly four kinds of environmental problems: environment acidification, eutrophication, global warming and the limited resource consumption.

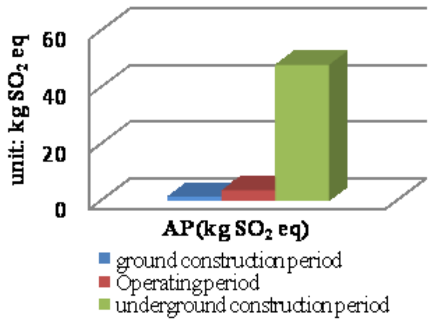

Figure 5a: the acidification results

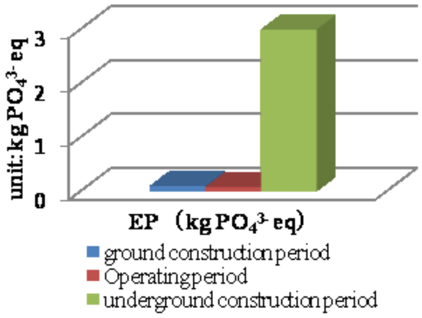

Figure 5b: Eutrophication results

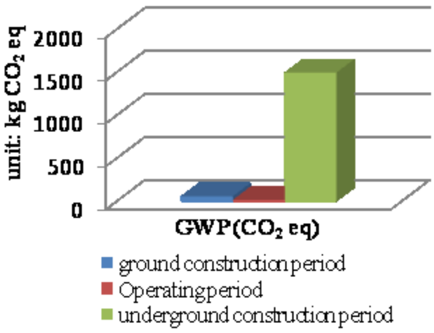

Figure 5c the global warming results

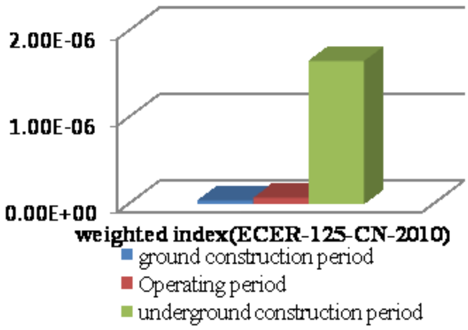

Figure 5d Weighted aggregative index results

Figure 5: the main environmental impacts of hydrothermal heating project through the life cycle

In the life cycle environmental impact assessment of hydrothermal heating project, the underground construction period has the largest influence on environmental acidification. In this period, projects such as drilling and cementing need to consume large amounts of diesel and cement and emit sulfur dioxide and other substances (Guo, M.J., Ding, J.et al, 2013). Operating period has the minimized influence on environment. It is mainly because that the main consumption during the period is electric energy and groundwater, and little sulfur dioxide is emitted. Eutrophication caused in the underground construction period and geothermal well retirement period have a relatively large proportion, due to a wide use of some substance such as cement. In addition, carbon dioxide and other greenhouse gas emissions are mainly concentrated in the underground construction period and on-the-ground construction period. Underground construction period has a larger amount of crude oil consumption, greater emission of greenhouse gases. So that it accounts for a significant global warming.

Table 5: The contributions to the environmental impact of different process of deep geothermal energy

Process name	AP(kg SO_2 eq)	EP(kg PO_4^{3-} eq)	GWP(kg CO_2 eq)	ECER-125-CN-2010
underground construction period	90.196%	94.001%	94.786%	93.800%
ground construction period	2.840%	3.082%	3.911%	2.182%
Operating period	6.961%	2.914%	1.299%	4.016%
decommissioning	0.004%	0.003%	0.004%	0.002%

According to formula (5), environmental impact of different construction stages are calculated.

The environmental impact of construction period accounted for 95.982% of the total effect, among which the operation period and retirement period have smaller environmental impact. In underground construction period, because of the depth of the well drilling and large consumption of diesel and cement in drilling and cementing, CO_2 and SO_2 equivalent are both large. Therefore, formulating standards for geothermal energy development and utilization, increasing the utilization level of engineering technology, and reducing pollution in the construction are in line with the principle of clean energy.

4.3 Comprehensive efficiency evaluation of geothermal heating in northern area

All resources, economy and environmental elements in geothermal energy utilization in north China are gathered. By using mutation series, it is calculated that total indicators are all above 0.8, and the order is Xiongxian, Xianyang, and Tianjin(from high to low), shown in table 6.

Table 6: Primary index calculation table

Index	Xiongxian	Xianyang	Tianjin
Overall performance	0.9493	0.9063	0.8866
Economic indicators	0.9068	0.8095	0.7389
Environmental indicators	0.7478	0.7776	0.6428
Energy consumption indicators	0.9221	0.7836	0.7714

From the point of economic indicators, Xiongxian is optimal for 0.9068. From the point of environmental benefits, environmental benefit index of Xiongxian(0.7478) is lower than environmental benefit index of Xianyang(0.7776), indicating that although increased spending on economy have influenced some part of the economic benefits of some of the project, it can be compensated by the benefit from less emissions and consumption. So, the final comprehensive efficiency was still high.

Comprehensively, low temperature geothermal resources are widely distributed in northern China. And due to the geographical distribution, the heating market is in huge demand. Therefore, hydrothermal heating in north China region has already reached a certain scale. Due to the supply of traditional energy being increasingly tense and higher fuel prices, geothermal heating in north China region has great development potential.

In terms of development scale, XiongXian and Tianjin are both located in north China plain. Tianjin has a larger size, longer history of geothermal heating, and relatively scattered geothermal heating project. It is the newly built geothermal heating demonstration area in Xiongxian that has more advantages in exerting the economic scale of geothermal development. In terms of resource usage, the higher the temperature, the better the heating quality, but that doesn't mean higher efficiency. Geothermal water temperature distribution in China's northern region are between 65 ~ 90 ^{o}C, it can meet the needs of geothermal heating, but the difficulty of extracting hot water is determined by water level height. Therefore, tail water recharge engineering has important impact on resource usage for a long time. In terms of heating technology, existing geothermal heating projects in northern China are mainly one-time heat transfer. New projects pay more attention to technologies that reduce the temperature of tail water injection and cascade development and utilization, improve efficiency by peak shaving, so as to promote the economic benefit, environmental benefit and efficiency of resources usage of geothermal heating in northern China.

5. CONCLUSION

Hydrothermal heating is the main form of exploitation and utilization of geothermal energy in northern China.

Based on the comprehensive analysis of environmental and economic impact assessment of geothermal heating projects in typical cities, it can be concluded that geothermal development in northern China has a huge market potential.

Geothermal heating project in northern China has good economic benefit. The average payback period is 5 years, input and output is of high efficiency and stable returns. Most new geothermal heating projects has the characteristics of centralized planning and can obtain greater economies of scale in the process of the geothermal exploitation and utilization.

Compared with conventional fuel, geothermal heating has great effect on reduction of greenhouse gas emission. But due to the imperfection of related standards on geothermal exploitation and utilization, the different construction technology level, environment acidification and environmental impact global warming comes from geothermal engineering construction period, accounting for about 95.98% of the total environmental impact.

Low temperature geothermal resource development in China's northern region has huge potential. Resources, economy and environment elements are gathered, indicating that typical urban comprehensive benefit index of geothermal heating project are all above 0.88, among which, the projecting manifestation of the energy consumption index of geothermal heating project has strong competitiveness.

With the development of technology, geothermal energy development and utilization mode in the northern area has become increasingly diverse. Some cities have already began to explore the ground source heat pump heating engineering and the low temperature geothermal power test. Due to different resources types and usage methods, its potential evaluation and benefit evaluation method is different, too. Follow-up studies can focus on the diversified characteristics of geothermal energy in northern areas, improving the research of geothermal energy development and utilization in northern China.

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