Economic and Environmental Impacts of Geothermal Resource Development in Hunan, China

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ABSTRACT

The global warming and soaring energy consumption have motivated many scholars and policymakers to pursue energy conservation and environmental improvement. As a renewable cleaning energy, geothermal resources have been actively developed in recent years. Taking six geothermal projects in Hunan, China as examples, this paper determines the input and output indices for each project. The input indices cover both economic and environmental dimensions. Then, the authors deeply explored how much geothermal resource quantity, single-well yield, total investment, and annual cost investment influence dynamic investment recovery period, coal reduction of summer operation, coal reduction of winter operation, environmental protection and energy saving, standard coal reduction, and emission reduction. The results show that total investment, single-well yield, and total investment have significant effects on economic indices, while geothermal resource quantity, single-well yield, and total investment have significant effects on environmental indices.

1. INTRODUCTION

As the globe gets warmer in recent years, more and more people become aware of environmental and energy problems. As a renewable cleaning energy, geothermal resources have achieved unprecedented development. The ground source heat pump (GSHP) is now widely recognized as an effective technique to use shallow geothermal energy for air conditioning.

The performance of a geothermal project could be affected by various factors of the local region, such as climate, geology, and geothermal condition. To design effective GSHP systems, many scholars have studied how different factors affects system performance [1, 2]. Some discovered that the seasonal variation in ambient temperature often leads to the imbalance between cooling and heating loads of buildings [3]. When the GSHP system is implemented in buildings with a large cooling load in hot regions, more energy is injected into the ground than the energy absorbed from the ground each year. The energy accumulated in the ground will push up surface temperature, and, with the elapse of time, dampen system performance.

Zhang et al. [3] researched five GSHP systems for residential buildings in hot summer and cold winter regions, and looked at the changes of the coefficient of performance (COP) and energy efficiency ratio (EER) of the heat pumps. Casasso et al. [4] evaluated the hallow geothermal potential of Cerkno with a climate-based method, and discovered that the COP of the GSHP system has a strong correlation with the annual mean temperature and the number of heating days.

The evaluation of geothermal potential is critical to the planning and installation of GSHP systems. By the geothermal technology of the application, shallow geothermal resources can be divided into closed loop and open loop systems [5]. Relying on geographic information system (GIS), Viesi et al. [6] assessed and plotted the shallow geothermal potential in mountains and valleys. The geothermal potential of the GSHP system depends on temperature and water availability [7].

In practical applications, the thermal performance of the GSHP system is susceptible to the heat transfer process, which is highly sensitive to the surrounding conditions (e.g., hydrogeology, geology, and geothermal condition) [8]. This opinion is agreed by many scholars [9-11]. Luo et al. [12] evaluated three different GSHP systems in Wuhan, and demonstrated that the field conditions determine the potential of these systems.

Focusing on the external factors of geothermal projects, the above studies show that the performance of the geothermal system depends on climate, geology, and geothermal condition. However, few scholars have studied the economic and environmental factors affected by geothermal projects, starting from the projects themselves [13-15].

Therefore, this paper intends to measure how geothermal projects affect economy and environment. For this purpose, six geothermal projects were selected from Hunan Province, which boasts a huge reserve of geothermal resources. Recent years has seen this province launching a series of geothermal development projects. To realize the sustainable development of renewable resources, it is critical to explore how to effectively utilize the geothermal resources in Hunan.

The remaining parts of this paper are arranged as follows: Part 2 summarizes the distribution and utilization of geothermal resources in Hunan; Part 3 introduces the input and output indices of the six geothermal projects; Section 4 discusses how much geothermal resource quantity, single-well yield, total investment, and annual cost investment influence

dynamic investment recovery period, coal reduction of summer operation, coal reduction of winter operation, environmental protection and energy saving, standard coal reduction, and emission reduction; Section 5 offers suggestions on the effective development of geothermal resources in Hunan.

2. OVERVIEW OF HUNAN'S GEOTHERMAL RESOURCES

Hunan Province has a wealth of geothermal resources, and thus an immense potential of geothermal development. Survey data show that geothermal resources are distributed across the 14 prefectures of the province. The annual exploitable amount of shallow geothermal resources alone is equivalent to 149.9128 million tons of standard coal (TCE), that of medium-deep geothermal resources (hydrothermal type) is equivalent to 352,700 TCE, and that of deep geothermal resources (hot dry rock) is equivalent to 237 million TCE.

Currently, the shallow geothermal resources of Hunan are the most suitable for mass development and utilization. The medium-deep geothermal resources have a small potential and a high difficulty in development. The deep geothermal resources are still being surveyed. The time is not yet ripe for developing deep geothermal resources.

The abundant shallow geothermal resources are distributed widely across Hunan. The huge reserve and high utilization ratio make the resources very suitable for development and utilization. The shallow geothermal resources can be divided into four systems:

(1) Groundwater GSHP system

According to survey data, Changsha, Yueyang, Changde, Zhuzhou, and Yiyang are the only five prefectures in Hunan suitable for developing groundwater GSHP systems. It is estimated that the groundwater GSHP systems in the five prefectures can yield 517.18×10^{14}J of heat each year, i.e., 2.9449 million TCE.

(2) Buried pipe GSHP system

Most of Hunan is fit for developing buried pipe GSHP systems. It is estimated that buried pipe GSHP systems across the 14 prefectures of Hunan can yield an annual amount of $24,204.31 \times 10^{14}$J, equivalent to 137.8221 million TCE.

(3) Surface water source heat pump (WSHP) system

Hunan is rich in water resources. The countless rivers, lakes, and reservoirs bring a huge potential of cooling and heating. It is estimated that surface WSHP systems across the 14 prefectures of Hunan can yield 947.19×10^{14}J of heat annually, about 5.3934 million TCE.

(4) Sewage WSHP system

Survey data show that, each year, 141.28×10^{14} of heat can be utilized from the sewage discharged by the 14 prefectures of Hunan, that is, 804,500 TCE.

So far, Hunan has built 198 shallow geothermal projects, which provide cooling/heating to 2.9554 million km^2 of buildings. Among them, 191 GHSP projects serve 2.8105 million km^2 of buildings, and 7 WSHP projects serve 144,900 km^2 of buildings. Every year, shallow geothermal projects help

Hunan to save 4,128.18 kWh of electricity, reduce coal consumption by 14,448.60 TCE, cut down carbon emissions by 3,7979.62 tons, lower sulfur dioxide emissions by 331.486 tons, slash nitrogen oxide emissions by 284.86 tons, and decrease dust emissions by 138.30 tons. The shallow geothermal resources are mainly utilized for cooling and heating buildings, and rarely used for other purposes.
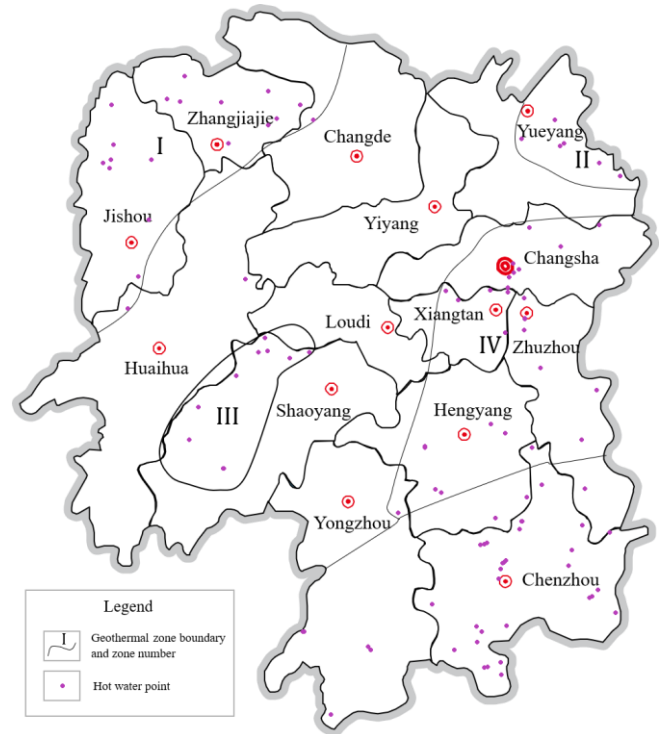

Figure 1. Underground hot water zones of Hunan

3. DATA COLLECTION

This paper collects the data related to six geothermal projects in Hunan. As shown in Table 1, the input indices include geothermal resource quantity (10^4m^3/a), single-well yield (m^3/d), total investment (10,000 yuan) (mainly including survey cost, geological assessment report cost, geothermal heat pump cost, purchase cost of equipment for machine room, purchase and installation cost of distribution and control equipment for machine room, purchase cost of other equipment, outdoor engineering consumable cost, outdoor engineering construction cost, pump room construction cost, etc.), and annual cost investment (10,000 yuan) (mainly including purchasing cost of raw materials and accessories, depreciation cost, wage and welfare cost, electricity bill, maintenance cost, mineral resource tax, other management costs, etc.). The output indices include dynamic investment recovery period (year), coal reduction of summer operation (ton/year), coal reduction of winter operation (ton/year), environmental protection and energy saving (10,000 yuan), standard coal reduction (ton/year), and emission reduction (ton/year).

Table 1. Input and output indices of the six geothermal projects in Hunan

Index		Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
	Geothermal resource quantity	51.77	56.38	101.2	62.82	49.52	60.25
	Single-well yield	2,488	1,795	3,651	1,700	2,579	1,648
Input index	Total investment	17,832	10,298	18,523	7,725	12,550	15,820
	Annual cost investment	7,254	5,961	4,682	3,881	4,006	4,823
	Dynamic investment recovery period	5.08	4.58	5.21	4.59	4.62	5.01
Output index (economy)	Coal reduction of summer operation	170	110	255	79.18	140.76	130.88
	Coal reduction of winter operation	165	96.24	262	94.6	40.43	111.93
	Environmental protection and energy saving	680	524	798	425	410	582
	Standard coal reduction	520	370.24	1,160.1	11.78	290.19	420.81
Output index (environment)	Emission reduction	1,300	861.11	900.25	29.46	470.96	1,070.03

4. DATA ANALYSIS

The collected data were subjected to correlation analysis on SPSS Statistics 24. The data analysis focuses on how much geothermal resource quantity, single-well yield, total investment, and annual cost investment influence dynamic investment recovery period, coal reduction of summer operation, coal reduction of winter operation, environmental protection and energy saving, standard coal reduction, and emission reduction. For the lack of space, this part only presents the analysis results on the degrees of influence of geothermal resource quantity, single-well yield, total investment, and annual cost investment over dynamic investment recovery period, as well as those of geothermal resource quantity, single-well yield, total investment, and annual cost investment over emission reduction.

4.1 Correlation analysis on dynamic investment recovery period

Based on SPSS Statistics 24, the authors analyzed the correlation between geothermal resource quantity and dynamic investment recovery period. As shown in Table 2, the Pearson correlation coefficient between the two variables was 0.580, which is below the threshold (0.75) for significant influence. Therefore, geothermal resource quantity does not significantly affect dynamic investment recovery period.

The authors further analyzed the correlation between single-well yield and dynamic investment recovery period. As shown in Table 3, the Pearson correlation coefficient between the two variables was 0.598, indicating that single-well yield does not significantly affect dynamic investment recovery period.

Next, the authors analyzed the correlation between total investment and dynamic investment recovery period. As shown in Table 4, the Pearson correlation coefficient between the two variables was 0.941, suggesting that total investment has a significant impact on dynamic investment recovery period.

The authors went on to analyze the correlation between annual cost investment and dynamic investment recovery period. As shown in Table 5, the Pearson correlation coefficient between the two variables was 0.348, i.e., annual cost investment does not significantly affect dynamic investment recovery period.

Table 2. Results on the correlation between geothermal resource quantity and dynamic investment recovery period

	Correlations		
		Geothermal resource quantity	Dynamic investment recovery period
Geothermal resource quantity	Pearson correlation	1	.580
	Sig. (2-tailed)		.227
	Sum of squares and cross-products	1,815.895	15.670
	Covariance	363.179	3.134
	N	6	6
Dynamic investment recovery period	Pearson correlation	.580	1
	Sig. (2-tailed)	.227	
	Sum of squares and cross-products	15.670	.401
	Covariance	3.134	.080
	N	6	6

Table 3. Results on the correlation between single-well yield and dynamic investment recovery period

	Correlations		
		Dynamic investment recovery period	Single-well yield
Dynamic investment recovery period	Pearson correlation	1	.598
	Sig. (2-tailed)		.210
	Sum of squares and cross-products	.401	653.562
	Covariance	.080	130.712
	N	6	6
Single-well yield	Pearson correlation	.598	1
	Sig. (2-tailed)	.210	
	Sum of squares and cross-products	653.562	2,977,894.833
	Covariance	130.712	595,578.967
	N	6	6

Table 4. Results on the correlation between total investment and dynamic investment recovery period

	Correlations	Dynamic investment recovery period	Total investment
Dynamic investment recovery period	Pearson correlation	1	.941**
	Sig. (2-tailed)		.005
	Sum of squares and cross-products	.401	5,763.293
	Covariance	.080	1,152.659
	N	6	6
Total investment	Pearson correlation	.941**	1
	Sig. (2-tailed)	.005	
	Sum of squares and cross-products	5,763.293	93,375,831.330
	Covariance	1,152.659	18,675,166.270
	N	6	6
	**. Correlation is significant at the 0.01 level (2-tailed).		

Table 5. Results on the correlation between annual cost investment and dynamic investment recovery period

	Correlations	Dynamic investment recovery period	Annual cost investment
Dynamic investment recovery period	Pearson correlation	1	.348
	Sig. (2-tailed)		.498
	Sum of squares and cross-products	.401	636.722
	Covariance	.080	127.344
	N	6	6
Annual cost investment	Pearson correlation	.348	1
	Sig. (2-tailed)	.498	
	Sum of squares and cross-products	636.722	8,315,278.833
	Covariance	127.344	1,663,055.767
	N	6	6

4.2 Correlation analysis on emission reduction

Based on SPSS Statistics 24, the authors analyzed the correlation between geothermal resource quantity and emission reduction. As shown in Table 6, the Pearson correlation coefficient between the two variables was 0.040, which is below the threshold (0.75) for significant influence. Therefore, geothermal resource quantity does not significantly affect emission reduction.

The authors further analyzed the correlation between single-well yield and emission reduction. As shown in Table 7, the Pearson correlation coefficient between the two variables was 0.225, indicating that single-well yield does not significantly affect emission reduction.

Next, the authors analyzed the correlation between total investment and emission reduction. As shown in Table 8, the Pearson correlation coefficient between the two variables was

0.805, suggesting that total investment has a significant impact on emission reduction.

The authors went on to analyze the correlation between annual cost investment and emission reduction. As shown in Table 9, the Pearson correlation coefficient between the two variables was 0.789, i.e., annual cost investment has a significant effect on emission reduction.

For the lack of space, the correlation analysis on other economic and environmental indices are not presented here. Table 10 sums up the correlation coefficients between geothermal resource quantity, single-well yield, total investment, and annual cost investment, and dynamic investment recovery period, coal reduction of summer operation, coal reduction of winter operation, environmental protection and energy saving, standard coal reduction, and emission reduction.

Table 6. Results on the correlation between geothermal resource quantity and emission reduction

	Correlations	Emission reduction	Geothermal resource quantity
Emission reduction	Pearson correlation	1	.040
	Sig. (2-tailed)		.939
	Sum of squares and cross-products	1,033,985.263	1,752.020
	Covariance	206,797.053	350.404
	N	6	6
Geothermal resource quantity	Pearson correlation	.040	1
	Sig. (2-tailed)	.939	
	Sum of squares and cross-products	1,752.020	1,815.895
	Covariance	350.404	363.179
	N	6	6

Table 7. Results on the correlation between single-well yield and emission reduction

	Correlations	Emission reduction	Single-well yield
Emission reduction	Pearson correlation	1	.225
	Sig. (2-tailed)		.668
	Sum of squares and cross-products	1,033,985.263	394,749.412
	Covariance	206,797.053	78,949.882
	N	6	6
Single-well yield	Pearson correlation	.225	1
	Sig. (2-tailed)	.668	
	Sum of squares and cross-products	394,749.412	2,977,894.833
	Covariance	78,949.882	595,578.967
	N	6	6

Table 8. Results on the correlation between total investment and emission reduction

	Correlations	Emission reduction	Total investment
Emission reduction	Pearson correlation	1	.805
	Sig. (2-tailed)		.053
	Sum of squares and cross-products	1,033,985.263	7,911,806.983
	Covariance	206,797.053	1,582,361.397
	N	6	6
Total investment	Pearson correlation	.805	1
	Sig. (2-tailed)	.053	
	Sum of squares and cross-products	7,911,806.983	93,375,831.330
	Covariance	1,582,361.397	18,675,166.270
	N	6	6

Table 9. Results on the correlation between annual cost investment and emission reduction

	Correlations	Emission reduction	Annual cost investment
Emission reduction	Pearson correlation	1	.789
	Sig. (2-tailed)		.062
	Sum of squares and cross-products	1,033,985.263	2,312,367.142
	Covariance	206,797.053	462,473.428
	N	6	6
Annual cost investment	Pearson correlation	.789	1
	Sig. (2-tailed)	.062	
	Sum of squares and cross-products	2,312,367.142	8,315,278.833
	Covariance	462,473.428	1,663,055.767
	N	6	6

Table 10. Correlation coefficients between geothermal resource development and economic and environmental indices

	Dynamic investment recovery period	Coal reduction of summer operation	Coal reduction of winter operation	Environmental protection and energy saving	Standard coal reduction	Emission reduction
Geothermal resource quantity	0.580	0.734	0.841	0.693	0.799	0.040
Single-well yield	0.598	0.931	0.710	0.666	0.846	0.225
Total investment	0.941	0.803	0.708	0.858	0.812	0.805
Annual cost investment	0.348	0.170	0.278	0.465	0.203	0.789

5. CONCLUSIONS

Starting from the basic attributes of geothermal projects, this paper explores how much the four dimensions of such projects, namely, geothermal resource quantity, single-well yield, total investment, and annual cost investment, affect the economy (dynamic investment recovery period, coal reduction of summer operation, and coal reduction of winter operation) and environment (environmental protection and energy saving, standard coal reduction, and emission reduction).

The results show that total investment has a significant impact on dynamic investment recovery period (correlation coefficient: 0.941); single-well yield and total investment have a relatively significant impact on coal reduction of summer operation (correlation coefficient: 0.931 vs. 0.803); geothermal resource quantity has a significant impact on coal reduction of winter operation (correlation coefficient: 0.841); total investment has a relatively significant impact on environmental protection and energy saving (correlation coefficient: 0.858); geothermal resource quantity, single-well yield, and total investment have a relatively significant impact on standard coal reduction (correlation coefficient: 0.799 vs.

0.846 vs. 0.812); total investment and annual cost investment have a relatively significant impact on emission reduction (correlation coefficient: 0.805 vs. 0789).

If the geothermal project developer wants to recover the investment cost soon, it must focus on the control of total investment; if the developer wants to save coal, it should try to improve geothermal resource quantity and single-well yield, both of which have a significant coal-saving effect.

Our analysis results also indicate that total investment significantly affects environmental protection and energy saving, and emission reduction. The main reason lies in the scale effect of geothermal resource projects, which mostly have a large total investment. Such projects also promote environmental protection and energy saving, and emission reduction. Considering the single utilization of geothermal resources in Hunan, the relevant departments are suggested to concentrate their technical strength to study the comprehensive utilization of geothermal resources, and carry out tests to explore new development schemes for such resources.

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