Study on Geothermal Energy Utilization Technology evaluation Based on AHP and Multi-Level Fuzzy Comprehensive Evaluation

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Abstract. Geothermal energy will play an important role in the energy supply and environmental protection. The paper study on geothermal energy utilization technology evaluation based on AHP (Analytic Hierarchy Process) and multi-level fuzzy comprehensive evaluation by setting up the evaluation model. The evaluation objects are mainly flash steam plants, dry steam plants, binary plants and heat pumps. According to the comprehensive assessment results, the paper determines priorities, analyzes the advantages and drawbacks of various technologies, and proposes the countermeasures on the further developing of geothermal energy technologies.

1. Introduction
Renewable energy is playing an increasingly important role in the energy security and social progress. Renewable energy development is no longer a fringe business, which is of high cost and low efficiency in the past. Almost all countries are developing or have completed implementation plans for renewable energy. Geothermal energy, a kind of clean and sustainable energy, will play an important role in the energy supply and environmental protection. About 700MW of new geothermal power generating capacity came on line, for a total approaching 12.8 GW in 2017. Even though the growth rate of geothermal energy is not as remarkable as that of solar and wind energy, the investment in renewable energy in some countries increases by varying degrees [1-5].

In China, the government plans to increase the sustainable use of geothermal energy in cities to reduce local air pollution and greenhouse gas emissions. As of 2015, China had less than 30 MW of geothermal power capacity, mostly in Tibet, but the country’s 13th Five-Year Plan for geothermal energy calls for an additional 500MW by 2020[4]. More than 4,000 hot spots have been found in China, more than 700 geothermal fields have been explored and more than 2,000 geothermal Wells have been drilled. The geothermal reserves identified are equivalent to 31.66 million tons of standard coal, and it is estimated that the reserves are 11.66 million tons of standard coal. China is the most significant user of direct geothermal heat and is short of geothermal power generation meanwhile.
The paper sets up the AHP (Analytic Hierarchy Process) model for comprehensive assessment of geothermal energy technologies and analyzes the strengths and weaknesses of various forms of geothermal energy utilization.

2. Major geothermal technologies
Geothermal energy is stored in rock and in trapped vapor or liquids, it can be used for generating electricity and providing heat and cooling. Electricity generation usually requires geothermal resources temperatures of over 100°C. The relatively low-temperature geothermal medium can be used for heating. Space cooling can also be supplied through geothermal heat.

2.1. Geothermal power generation
Geothermal power generation is a new kind of power generation technology which utilizes underground hot water and steam as power source. Its basic principle is similar to that of thermal power generation. It is actually a process of transforming underground heat into mechanical energy, and then transforming mechanical energy into electric energy.

Geothermal power plants can use water in the vapor phase, a combination of vapor and liquid phases, or liquid phase only. The choice of plant depends on the depth of the reservoir and the temperature, pressure and nature of the entire geothermal resource. The three main types of plant are dry steam, flash steam, and binary plants.

Flash steam plants is the power generation system that directly uses the steam generated by underground hot water to drive the steam turbine to do work and then convert the mechanical energy into electrical energy. The use of underground hot water below 100 °C to generate electricity mainly utilizes the relationship between the boiling point of water and the pressure. This system is making up about two-thirds of geothermal installed capacity today.

Dry steam plants, which make up about a quarter of geothermal capacity today, directly utilize dry steam that is piped from production wells to the plant and then to the turbine. The dry steam is taken out from the steam well, and after separating the solid impurities (≥ 10μm) through the separator, it enters the steam turbine to do work and drives the generator to generate electricity. The power generation equipment used in dry steam power plants is basically the same as conventional thermal power equipment.

Binary plants, using an organic Rankine cycle (ORC) or a Kalina cycle, typically operate with temperature varying from as low as 73°C to 180°C. The Rankine cycle mainly includes isentropic compression, isobaric heating, isentropic expansion, and an isobaric condensation process. As the heat transfer performance of low boiling point working medium is worse than that of water, the metal consumption is large. In addition, the high price of organic working materials, limited sources, also affect the economy to some extent [6-9].
2.2. **Geothermal heat pump**

Geothermal heating represents a significant share of geothermal energy consumption. Geothermal heat use can cover several types of demand at different temperature levels. Even geothermal resources at temperatures of 20°C to 30°C may be useful to meet space heating demand.

Geothermal heat pump is a rapidly developing technology for geothermal utilization. Heat pump is a kind of heat lifting device. It consumes a small part of electric energy while working, but it can extract 4-7 times of electric energy from water and steam. Geothermal heat utilization has high heat utilization rate of 50%-70%, with significant advantages of short construction period and relative less fund. Meanwhile, geothermal steam and hot water are difficult to transport over long distances and their utilization is limited by the distribution area. Geothermal district cooling is poorly developed but could provide a summer use for geothermal district heating systems. Geothermal heat above 70°C can produce chilled water in sorption chillers that can be piped to consumers via the same circuit used for heating. Alternative devices such as fan coils and ceiling coolers can also be used. Sorption chillers have recently become available that can be driven by temperatures as low as 60°C, enabling geothermal heat drive compression chilling machines in place of electricity[10].

3. **Development of AHP model**

We decompose relevant factors into several levels such as objectives, criteria and schemes. By comparing the relative importance of the two factors, we give corresponding proportions, construct judgment matrix, and implement the objective quantification of subjective judgments of different factors, and obtain the weights of different factors or objects at last.

As the fig.4 shows, we set up AHP model to analyze the advantages and disadvantages of different technologies, including 4 levels. These 4 levels are objectives, criteria level, the sub-criteria level and the relative technologies. The objective level is to determine the weight of each technology by calculating and comparing kinds of technical weights. The criteria level consists of energy conservation, pollutants reduction, GHG (greenhouse gas) reduction, technical performance and economic performance. The evaluation indexes of energy conservation consist of the amount of energy saving, the amount of power saving, reflecting the current value and potential of a technology in terms of energy efficiency. The pollutants reduction mainly includes the emission decrease of SO2, NOx, dust and other wastes. Energy saving and emission reduction is an important part of evaluating an energy utilization technology. The environmental protection of geothermal energy utilization technology is very important. The role of greenhouse gas emission reduction is an important reason for the development of renewable energy. The technical performance of a product reflect usage requirements and possibility of large-scale use, it is very important to its development and promotion. The economic performance is an important criteria for comparison. We focus on the construction costs, operation, administration and maintenance costs, internal rate of return, and payback period.
The priority and ranks for main criteria and sub-criteria is shown in Table 1. Each judge grades each index according to the evaluation index system, and then gets the weight of each factor.

### Table 1. Synthesized priorities and ranks for criteria

| Main criteria               | Sub-criteria               | Priority | Rank |
|-----------------------------|----------------------------|----------|------|
| Energy conservation (0.2102)| Energy saving              | 0.1051   | 2    |
|                             | Power saving               | 0.1051   | 2    |
| Pollutants reduction (0.1450)| SO₂                        | 0.0370   | 13   |
|                             | NOx                        | 0.0370   | 13   |
|                             | Dust                       | 0.0463   | 10   |
|                             | Other wastes               | 0.0247   | 15   |
| GHG Reduction (0.1911)      | CO₂ reduction              | 0.1274   | 1    |
|                             | Other GHG reduction        | 0.0637   | 7    |
| Technical performance (0.2627)| Technology maturity       | 0.0952   | 4    |
|                             | Climate and geographical requirement | 0.0762 | 6 |
|                             | Large-scale application requirement | 0.0913 | 5 |
| Economic performance (0.1911)| Construction costs         | 0.0515   | 9    |
|                             | Running costs              | 0.0396   | 12   |
|                             | Internal rate of return    | 0.0429   | 11   |
|                             | Payback period             | 0.0572   | 8    |

### 4. Measurement and data collection

After building the AHP hierarchy, the next phase is the measurement and data collection, which involves forming a team of evaluators and, as explained above, assigning pairwise comparisons to the strategic factors, criteria and sub-criteria used in the AHP hierarchy. Qualitative descriptions or quantitative descriptions of main criteria and sub-criteria are important in the AHP evaluation process. In this stage, we use quantitative descriptions wherever possible, which can be obtained through literature research and counseling. This part can be directly used to assign pairwise comparisons of all elements in each level of the hierarchy. Some data, such as technical cost, varies from area to area, is determined according to the minimum value. For qualitative description parts, we collect relative information, and then ask five experts to mark to each sub-criteria.
5. Results

![Priority](image)

**Fig. 5** The priority of geothermal technology

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**Fig. 6** The technology priority corresponding to (1) energy conservation (2) pollutants reduction (3) GHG reduction (4) technical performance and (5) economic performance
Fig. 5 shows the priority of geothermal technologies. We can see that the arrangement of geothermal technology would be heat pump, flash steam plant, binary cycle plant and dry steam plant. The weight of ground source heat pump has very big advantage in comparison.

In order to further study and discuss the application prospect of each technology, we calculate the priority under every main criteria, as shown in Fig. 6. We can see that ground source heat pump technology has significant advantages in all aspects. This is largely due to that heat pump uses relatively constant temperature of water or steam. It is receiving increased attention and increased policy support in many countries. Ground source heat pump is a cost-effective energy-saving technology. The COP value of the ground source heat pump reaches 4 or more, that is to say, the energy of 1KWh is consumed, and the user can get more than 4KWh of heat or cold. The ground source heat pump has significant environmental benefits. The operation of the unit is free of any pollution and can be built in residential areas without burning, no smoke, no waste, no need to stack fuel waste, and no need to transport heat over long distances. It can be seen from the research results that the ground source heat pump will still be the main technology of geothermal energy utilization under the current technical and environmental conditions. With the development of economy and the improvement of people's living standard, the heating and air conditioning of public buildings and houses have become a common requirement. Ground source heat pump is an proper way to solve heat and air conditioning.

In terms of power generation, flash steam plant and binary cycle plant have advantages over dry steam in (1) energy conservation (2) pollutants reduction (3) GHG reduction. Flash steam plant developed rapidly in recent years, satisfying some need of electricity now.

Conclusion
The weight of ground source heat pump is 0.3304, showing obvious advantage in all aspects compared with geothermal generation technologies. The technology of flash steam plant and binary cycle plant shows a good development prospect and the technology of dry steam plant has better technical performance. The use of geothermal power generation needs further research and promotion.

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