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Performance measures in geothermal power developements

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ABSTRACT

Geothermal resource assessment requires several input parameters at a time when field information is normally very limited. The power plant efficiency is an important parameter as it affects investment cost and profit. However, there is significant debate in the geothermal industry on the appropriate performance measure to implement. In this paper we attempt to determine the best performance measures for financial decision making during the exploration stage of geothermal power developments. We compare and contrast current performance measures commonly used by the geothermal industry. This includes thermal efficiency, geothermal brine effectiveness, utilisation efficiency and enthalpy efficiency.

We show that enthalpy efficiency, categorised by the geothermal reservoir enthalpy, is the best financial performance measure because it is similar to other measures on most criteria, but superior in terms of comparability across different geothermal sites, while satisfying homoscedasticity. Utilisation efficiency, on the other hand, was demonstrated to have the least reliability while requiring additional input parameters.

We recommend using the modified enthalpy efficiency developed in this work for resource assessment of new geothermal fields, benchmarking with existing development and for comparison with conventional fossil-fuel thermal plants. This should also affect the choice of resource assessment methodology.

1. Introduction

Currently there is a significant debate in the geothermal industry around the issue of performance measures for geothermal power developments [1–4]. This debate centres around three commonly used performance measures in the geothermal industry: thermal efficiency [1,4], brine effectiveness[1] [6] and utilisation efficiency [4], and a newly suggested performance measure, which we refer to as enthalpy efficiency [1]. In brief, the proponents of utilisation efficiency argue that thermodynamically it is the most appropriate performance measure; while proponents of enthalpy efficiency argue that it is the most appropriate performance measure because it has good comparability between different geothermal power generation sites. Clearly, it is important for performance measures to be both theoretically linked to the desired outcome and to have a method which allows meaningful comparison between results.

In this paper, we evaluate various performance measures against their ability to indicate the financial performance of an investment in a geothermal development. To evaluate these different performance measures, we compare them against the following key characteristics of performance measures: 1. Is the performance measure theoretically linked to the desired performance result? 2. Does the performance measure have a meaningful method of comparison to indicate if current performance is valid or not? 3. Is the performance measure objective, quantifiable and measurable?

2. Background

2.1. Performance measures

Implicit in the term performance measures is the idea that there

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[1] Moya and DiPippo [4,5] refer to ‘specific brine consumption’ which is essentially the reciprocal of brine effectiveness.

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exists a performance that you wish to measure. However, depending on the organisation or process or individual, performance can have many meanings: for example, achieving targets, improving processes, reducing costs, increasing customer satisfaction and so forth.

In this light, it is unsurprising that the geothermal industry has multiple performance measures, and a debate around which is the most appropriate. One method of dealing with the issue of various definitions of performance is to ensure that performance measures have a clearly defined purpose and use. The concept of a performance measure implies that you have a goal for a specific process or project that you wish to monitor. The more accurately this specific process is defined (i.e. the boundaries, inputs and outputs are known), and the more clearly the goal for this process is understood, the more likely it is that an appropriate, agreed upon performance and performance measure will be found. In this paper, we use the following useful definition of performance (or efficiency) provided by Çengel and Boles [7],

$$\text{performance} = \frac{\text{desired output}}{\text{required input}}. \tag{1}$$

Given that we are interested in performance measures that indicate the financial performance of an investment in a geothermal development, we further consider this equation in monetary terms, which gives:

$$\text{performance} = \frac{\text{revenue}}{\text{cost}}. \tag{2}$$

As with profit, an organisation can only increase its performance by increasing revenue or decreasing cost. Hence, it is easy to see the relevance of this performance measure.

Depending on the author, performance measures are referred to by many names (key performance indicators (KPIs), performance indicators, metrics etc.). As there are different names, there are also slightly different definitions for performance measures [8–10]. However, there is general agreement that performance measures must have the following three characteristics: 1. a theoretical link to a stated performance goal, 2. comparability, 3. be quantifiable, measurable and objective.

2.1.1. Theoretical link to a stated performance goal

Many parameters are measured in business, but not everything that is measured is important to every project/process. It is important to choose a performance measure that accurately links to the stated goal for the specific process you wish to monitor [9]. Further, it is important to understand the limitations of any chosen performance measure. We will use equation (1) to link performance measures to performance goals.

2.1.2. Comparability

Performance measures must have a method of comparison which indicates if current performance is good or bad and the degree of this result (e.g. a benchmark). This means that one, single number cannot be a performance measure because it cannot indicate whether performance is good, bad or indifferent. Ideal and/or historic data are often used for comparability. Historic data is only useful for comparability when the variation in historic results is sufficiently small to allow for a judgement about current performance. Clearly, if the historic data has significant variation it is difficult (or impossible) to determine if current performance is good or not. Ideal performance is a performance level that generally cannot be achieved (as in an ideal Rankine cycle). Hence, without historic data, 'ideal performance' also cannot provide information on whether a result is good or bad. Other factors which affect the comparability of data are changes that occur between measurements. Hence, it is important to know which factors significantly affect the comparability of performance measurement data: for example, when data is collected from different locations.

2.1.3. Quantifiable, measurable and objective

This is required to ensure that comparisons are unbiased, repeatable, and reliable.

2.2. Levelised cost of energy

The levelised cost of energy (LCOE) is a widely accepted performance measure used to compare the cost competitiveness of electricity generation technologies [11–14]. In this section we define LCOE and discuss why it is a good performance measure.

Generally, electricity is considered a commodity because a consumer cannot tell the difference between electricity produced by one supplier versus electricity produced by a different supplier. While it is certainly true that the electrons that transfer electricity to our houses and factories are indistinguishable, electricity is distinguished based on: *when* it is produced (i.e. periods of peak or low demand) and *how* it is produced (i.e. using renewable or non-renewable resources).

Electricity is differentiated based on *when* it is produced because: 1. electricity demand changes significantly from day to night and season to season; 2. electricity cannot be cost-effectively stored in large quantities; and 3. cheaper methods of electricity production (i.e. large coal and nuclear fired power stations) cannot start, stop or change production quickly. This means that cheaper forms of electricity production cover the base-load demand for electricity, while more expensive forms of electricity production cover the intermediate and peaking demand [15].

In addition, electricity is increasingly differentiated based on how it is produced, particularly whether it is from renewable versus non-renewable energy sources. This change means that renewable (or green) electricity providers are increasingly able to charge a premium for their product. However, varying price according to how electricity is produced is still in its infancy and subject to the regulatory framework in which electricity producers operate [16–18].

Geothermal energy, like the popular renewable energy sources of wind and solar, is limited in its ability to quickly change production volumes on demand, hence cannot differentiate itself to provide electricity only at times of peak demand. However, unlike wind and solar, geothermal energy is known for its high availability [3], and hence providing base-load electricity. Geothermal energy is clearly a renewable energy source and as such could potentially receive a premium price for its electricity; however, since this kind of price differentiation depends significantly on the local regulatory framework, it will not be considered in this work. Hence, we consider that electricity produced by geothermal energy cannot be differentiated based on when or how it was produced. That is, geothermal energy producers cannot charge a premium for the electricity they generate. A good example is New Zealand, where geothermal energy accounts for around 16% of produced power and competes with all other power sources [19].

Using equation (2), organisations can only increase revenue by increasing price or increasing capacity. Since base-load electricity producers cannot differentiate their product, they cannot demand a higher price. Hence, the only way for base-load electricity producers to increase revenue is to increase capacity. This means that we can simplify equation (2) by replacing revenue with capacity, to give: