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# Evaluating the performance of thermal power enterprises using sustainability balanced scorecard, fuzzy Delphic and hybrid multi-criteria decision making approaches for sustainability

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ABSTRACT

The severe situation of resources and environment poses undesirable conditions to thermal power enterprises for making profits. To promote sustainable development, a novel hybrid framework for evaluating the performance of thermal power enterprises is proposed from the perspective of sustainability. Based on the principle of a sustainability balanced scorecard, the initial evaluation criteria are determined, in which the "environmental" and "sustainable" perspectives are covered to address issues of inadequate corporate social responsibility. Then, 22 final criteria are recognized using the fuzzy Delphi method. Considering the deficiencies of the sustainability balanced scorecard in perceiving importance criteria weights and achieving a comprehensive evaluation, a hybrid evaluation model that operates in the fuzzy environment is developed based on the analytic network process and the technique for order preference by similarity to an ideal solution. The relative weights of the evaluation criteria are computed by the analytic network process to address the interdependent relationships among the criteria. Furthermore, because of the simple and logical computation process, the fuzzy technique for order preference by similarity to an ideal solution is adopted to prioritize the performance of thermal power enterprises in terms of linguistic variables, which are capable of handling situations involving complex and ambiguous problems. Finally, the effectiveness of the proposed framework is demonstrated using a case study from the China Huaneng Group Corporation, in which the performances of four enterprises are effectively prioritized. The results indicate that the "sustainable" and "learning and growth" perspectives are the key elements that can greatly improve performance. The proposed framework can help authorities enhance the competitiveness of decisions for sustainable development. In addition, this study extends the scope of this type of issue through varying multi-criteria decision making tools and different environments such as uncertainty, gray and fuzzy.



## 1. Introduction

Because China is maintaining a high speed of development in the near term, a large amount of electricity needs to be supplied to meet the demands of social and economic development. Thermal power will continue receiving priority over power generation due to the dominance of coal resources in China. Currently, thermal power units account for 70% of the total installed capacity, which consumes large amounts of coal and water resources and imposes enormous strains on the environment (Bi et al., 2014). Moreover, due to the serious problems of environment conservation and sustainable development, the "green development" and "sustainable development" of thermal power enterprises have been the foremost concerns of the government (Lin and Yang, 2013). Recently, thermal power enterprises have suffered pressures and challenges from the "Twelfth five-year" plan and "Action plan for the control of air pollution." Therefore, it is essential to establish a framework that can evaluate the performance of thermal power enterprises from the perspective of sustainability. Such a framework would help managers understand the above-described situation and create solutions for developing forthcoming strategies, which is of great importance to the sustainable development of enterprises. This framework would also aid authorities in properly supervising the production status and guaranteeing the sustainability of the electric power industry in China.

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Different methods have been developed to comprehensively evaluate the performance of enterprises. The balance scorecard (BSC) method, introduced by Kaplan and Norton (1996), is well known as one of the most popular approaches in performance evaluation and considers financial factors as well as non-financial factors (Schauβ et al., 2014). Nevertheless, this method ignores the important aspect of sustainability in performance evaluation. Therefore, some scholars have modified the BSC and proposed a novel sustainability balanced scorecard (SBSC) to analyze the performance of corporations and that takes sustainability into account by incorporating environmental and social performance (Rabbania et al., 2014). Figge et al. (2002) integrated an SBSC into the general management of a business unit. Moller and Schaltegger (2005) embedded eco-efficiency indicators into an SBSC strategy map to estimate and control the appropriate key indicators of environmental and economic issues. However, combining the issues of sustainability with the BSC to evaluate the performance of thermal power enterprises has not been addressed in previous studies.

In this study, the SBSC concept is employed to determine the initial evaluation criteria for the performance of thermal power enterprises, which covers many perspectives, such as “economic,” “environmental,” “sustainable,” and “learning and growth”. Therefore, the initial criteria based on the SBSC can comprehensively measure and improve the sustainable performance of thermal power enterprises. Furthermore, the fuzzy Delphi method (FDM) is a group technique used to determine the final evaluation criteria through a series of intensive questionnaires with controllable opinion feedback. This method can yield the most reliable consensus opinion about the evaluation criteria and overcome the problems of ambiguity and uncertainty in experts' responses (Okan et al., 2012). Clearly, performance evaluations for thermal power enterprises are conducted based on multiple factors, thus constituting a multi-criteria decision making (MCDM) issue. In recent years, various methods have been proposed to assess the performance of thermal power enterprises, including the key performance indicator (KPI) method, the balanced scorecard method, the analytic hierarchy process (AHP), and data envelopment analysis (DEA) (Zhou et al., 2008; Shi and Yu, 2008; Liang et al., 2007; Li and Li, 2005). However, because they only consider a single indicator, the KPI and SBC methods fail to consolidate multiple performance indicators. In addition, these two methods have some deficiencies in perceiving the importance weights of the main criteria and subcriteria for the purpose of performance evaluation. To overcome these shortcomings, the AHP method has been applied to evaluate overall performance (Fletcher and Smith, 2004; Huang, 2009). However, the AHP method does not sufficiently consider the interdependencies among indicators. In addition, the DEA method limits the selection of evaluation criteria, and the results are greatly affected by extreme values.

The technique for order preference by similarity to an ideal solution (TOPSIS) is a multi-criteria decision-making method for evaluating and ranking alternatives against several conflicting criteria and has been applied to appraise the performance of enterprises (Atmaca, 2012; Rouhani et al., 2012). The evaluation result yielded by the TOPSIS technique not only considers the distance from the positive ideal but also takes the distance from the anti-ideal solutions into account. Moreover, due to the simple and logical computation process, the results can be obtained in less time than other approaches when the index system is enormous and complex, such as the AHP and the analytic network process (ANP) (Ju et al., 2015).

Evaluating the performance of thermal power enterprises based on SBSC is highly complicated and requires consideration of numerous factors, ranging from macro-scale to micro-scale aspects. Qualitative and quantitative data always exist simultaneously in real multiple criteria assessment situations. However, TOPSIS is usually criticized for handling the inherent uncertainty involved in the process of multi-criteria decision making problems. To overcome the shortcomings of the traditional TOPSIS, the fuzzy logic technique can be adopted to address situations involving complex and ambiguous problems (Wang and Elhag, 2006, Herman et al., 2014, Satar et al., 2014, Tabasam et al., 2014). As a result, considering the characteristics of the problem and evaluation methods, the fuzzy TOPSIS is employed to analyze the performance of thermal power enterprises in this paper.

The performance evaluation of thermal power enterprises based on the SBSC is a complex problem covering multifarious criteria and complicated relations. The ANP is an appropriate tool for incorporating dependencies and feedback using a hierarchical decision network, which can represent and synthesize mutual effects through a single logical procedure (Sarkis and Sundarraj, 2002). Thus, the ANP technique is well suited to address the problem examined in this paper and provides advantages in formulating the weights of evaluation criteria with interdependency relationships.

The main contribution of this paper is the construction of a framework for evaluating the performance of thermal power enterprises from a new perspective of sustainable development. To promote the sustainability of thermal power enterprises, the initial evaluation criteria are determined based on SBSC, which not only takes regular factors into account but also considers environmental and sustainable parameters with linguistic variables. On this basis, the FDM technique is employed to formulate the final evaluation criteria from experts' opinions. The evaluation model is developed based on ANP and fuzzy TOPSIS method, which fully takes advantage of ANP in solving complex problems and the fuzzy TOPSIS in handling uncertainty and vagueness.

The remainder of this paper is organized as follows. The basic research methods are described in Section 2. Section 3 presents the framework of the proposed model. In Section 4, the applicability of the proposed model is demonstrated through the performance evaluation of four thermal power enterprises in the China Huaneng Group Corporation. Conclusions are drawn in the final section.

## 2. Research method

This section describes the SBSC method and defines the criteria structure for the performance evaluation of thermal power enterprises. In addition, the fuzzy Delphi and ANP techniques are presented briefly. Finally, the fuzzy TOPSIS is described in detail.

### 2.1. Sustainability balanced scorecard

The sustainability balanced scorecard (SBSC), derived from the traditional BSC, is described by Figge et al. (2002) to overcome the deficiencies of the conventional BSC in social, environmental and sustainable management systems. The BSC approach, as a corporation performance evaluation system, formulates a hierarchical system of strategic objectives from four main perspectives: financial, customer, internal process, and learning and growth. It is a comprehensive evaluation model that integrates physical and intangible assets and builds a relationship among different criteria. However, this approach ignores environmental, social and sustainable aspects.

Therefore, the SBSC structure was proposed to reflect the global performance based on the BSC, incorporating parameters related to sustainability. Moreover, the SBSC not only detects strategic environmental and social objectives of a corporation but also enhances the transparency of value-added potentials emerging from social and ecological aspects. As a result, Hsu et al.