ANALYSIS OF CRITICAL FACTORS IN ENERGY SERVICE CONTRACTING USING FUZZY COGNITIVE MAPPING

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Abstract

This study explores the critical factors influencing the energy service contracting market in Turkey. Fuzzy cognitive mapping that allows dynamic modeling of the behavior of uncertain and complex systems was used to model the energy service contracting system. Qualitative simulations were performed in order to predict changes in the system and to observe whether an equilibrium state is reached. The results reveal the factors to focus on that may contribute to the improvement of the energy service contracting market in Turkey.

Keywords: Fuzzy Cognitive Maps, Energy Service Contracting, Energy Efficiency

1. Introduction

The overall climate change, growing demand for and rising prices of energy resources, technological innovations and economic developments have led energy efficiency to become one of the prime concerns of many industries. In study we define energy efficiency as reducing the energy consumption without causing any decline in production quality and quantity in industrial establishments (see EIE, 2007). When firms decide to implement energy efficiency activities they may increase their productivity, avoid waste, reduce costs and emissions, and thereby gain competitive advantage. Energy efficiency activities can be either outsourced or they can be handled inside the firm by investing to the necessary assets such as workforce, equipment, technology, etc. Experience shows that energy service contracting, a form of outsourcing, plays a significant role in promoting energy efficiency (Sorrell, 2007). Such contracts can reduce many of the difficulties that firms often experience in planning, implementing and monitoring energy efficiency projects because they offer a comprehensive package of services. These services, provided by energy service companies (ESCOs), include identifying energy saving opportunities, purchasing energy commodities, financing, installing, training, commissioning and maintaining equipment, and monitoring. An ESCO guarantees energy savings to its clients and its payment is subject to the energy savings achieved (Okay et al., 2008).

There are various reasons for considering outsourcing and contracting services for an industrial energy consumer. In this paper, we explore the critical factors shaping the energy service contracting market in Turkey. In the past few years the energy industry in Turkey has undergone a change in terms of restructuring and deregulation. However, there are still some barriers hindering the development of this industry such as economic instability, capital inadequacy of local firms, unclear financing-mechanisms, uncompleted structural reforms, and insufficient knowledge of end-users, firms, and financing institutions (Onaygil and Meylani, 2007; Okay et al., 2008). To analyze the factors influencing energy service contracting and operations we utilized fuzzy cognitive mapping which allows modeling the behavior of a complex system of causal reasoning in form of a signed fuzzy diagraph. Experts who have knowledge and experience on energy service contracting were involved in the determination of the factors, their causal relationships and in the assignment of casual fuzzy weights to the relationships. The constructed fuzzy cognitive map (FCM) was used to perform qualitative simulations in order to predict reactions to possible changes in the system and to observe whether an equilibrium state is reached. The results provided the basis for developing recommendations for the energy service contracting market in Turkey.
2. Fuzzy Cognitive Maps

Fuzzy Cognitive Mapping, advanced by Kosko (1986) from the classical Cognitive Mapping Method, is an illustrative causative representation of complex systems and can be used to model and manipulate the dynamic behavior of systems (Papakostas et al., 2008). Combining elements of fuzzy logic and neural networks, fuzzy cognitive mapping has been proven to be a promising method for making inferences in cases with substantial uncertainty, imprecision and vagueness (Vasantha Kandasamy and Smarandache, 2003; Tsadiras, 2008). Most of the fuzzy cognitive map (FCM) models are constructed basically by expert knowledge and experience in the operation of the system. FCMs can be developed for a single expert or a group of experts, where the latter has the benefit of improving the reliability of the final model (Yaman and Polat, 2009). The aggregation of knowledge from multiple experts is a relatively simple process in fuzzy cognitive mapping (Stach et al. 2005). Each expert describes every interconnection with a fuzzy rule in terms of linguistic variables (weights) which are later composed (e.g. by averaging) to produce the combined map. Several procedures have been proposed for combining multiple FCM models into a single one (see e.g. Kosko, 1992; Stach et al., 2010).

A FCM can be represented either as a graph, consisting of concepts (e.g. entities, states, or characteristics of the system) and weighted interconnections between these concepts, or as an adjacency matrix, which has entries wij’s indicating the direct relationship between concept i and concept j. Figure 1 illustrates a simple FCM consisting of five concepts Ci (i=1, …,5) where wij represents the influence degree from cause Ci to effect Cj. FCM does not allow any direct connections between a concept and itself, thus all wii elements equal to zero. All other wij elements take values in [-1, 1] and Papageorgiou (2011) explains the meaning of these values as:

- wij > 0 indicates a causal increase (i.e., Cj increases as Ci increases, and Cj decreases as Ci decreases)
- wij < 0 indicates causal decrease (i.e., Cj decreases as Ci increases, and Cj increases as Ci decreases)
- wij = 0 indicates no causality

![Figure 1. A hypothetical FCM model and the corresponding adjacency matrix](image)

Each concept takes its initial value as , where i is the value of concept i at step k, and simulated iteratively. The value of each concept in an iteration is calculated as (Papageorgiou et al., 2009)

\[
i_{k+1} = \sum \left( f \left( w_{ij} \cdot i_k \right) \right)
\]

In Eq. (1), ic is the value of concept at step (k+1), ic is the value of concept at step (k), wij is the weight of interconnection between Cj and Ci, f is the threshold function (activation function) that reduces the result of the multiplication into a normalized range (within [0, 1]). The most common activation functions are (Tsadiras, 2008): bivalent, trivalent, sigmoid, hyperbolic tangent. In this study the sigmoid function: is used. By choosing the sigmoid function, not only the increase and decrease but also changes in the degree of a concept can be indicated (Tsadiras, 2008).
3. Analysis of Critical Factors in Energy Service Contracting

As explained above, in this study, we aim to explore the critical factors influencing the energy service contracting market in Turkey and the outsourcing decision of industrial energy consumers. In the past few years the energy industry in Turkey has undergone a change in terms of restructuring and deregulation. The Energy Efficiency Law (EEL) of Turkey came into force in May 2007. The Law was developed as a result of Turkey’s tasks of complying with the EU directives. It promotes the efficient use of energy and covers administrative structuring, energy auditing, financial instruments and incentives, awareness raising and the establishment of an ESCO market for energy efficiency services (EIE, 2007). With the EEL it is aimed to end the state monopoly and allow private-sector participation in energy industries, aiming at cost-effective pricing through competition (Okay et al., 2008). However, EEL regulations, particularly for the industrial energy consumers, were already being practiced since 1995. Currently, as of July 2011, there are 38 ESCOs in Turkey approved by the General Directorate of Electrical Power Resources Survey and Development Administration (EIE); 23 of which are certified for industrial projects. Although their project-financing mechanisms are not clear yet (Okay and Akman, 2010), these companies are familiar with outsource financing, energy accounting, energy auditing, budgeting, training and consulting for energy managers, energy monitoring and reporting. In the literature, there are two very informative studies about the ESCO market in Turkey. Onaygil and Meylani (2007) give an overview of energy service contracting and ESCOs and provide policy suggestions for the forthcoming Turkish ESCO market. Okay et al. (2008) present views with regard to the funding and related risks that are likely to be associated with the forthcoming Turkish ESCO market. Besides, there are studies focusing on the analysis of barriers and/or success factors of energy performance contracting projects in different countries (Bertoldi et al., 2005; Zhang et al. 2008).

3.1. Data Collection

A three-stage procedure (Nasserzadeh et al., 2008), see Figure 2, has been employed to construct the FCM of the energy service contracting market in Turkey. In the first stage, the relevant factors have been identified by reviewing the literature on energy service contracting and ESCOs. After a final examination, 23 factors remained (Figure 3). In the second stage, a two-round Delphi study involving four energy service contracting experts has been conducted. The Delphi method was applied with the purpose of reaching a consensus among experts regarding the relationships in the final cognitive map. The method provides feedback reports to experts, and, hence, the opportunity to improve their own opinion based on this feedback (Linstone & Turoff, 1975). In the third stage, the constructed cognitive map has been extended to a fuzzy cognitive map by assigning linguistic fuzzy weights for each interconnection. A questionnaire has been designed and used to collect the opinions of experts which results have been converted to linguistic fuzzy weights by using the fuzzy logic toolbox in MATLAB software. Figure 3 presents the FCM of the energy service contracting market in Turkey.

![Figure 2. The Three-Stage Data Collection Process (adapted from Nasserzadeh et al., 2008)](image-url)
3.2. Results

The constructed fuzzy cognitive map (FCM) was used to perform qualitative simulations in order to predict possible changes and to observe whether the system converges toward a steady state. Alternative scenarios have been considered for the simulation of the energy service contracting model. In each of the test scenarios the FCM was first initialized, i.e. the activation level of each factor in the map took a value between -1 and +1 based on experts’ opinions for the current state. For example, \( A^{(0)} = [1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0] \) is an initial vector state where only the factor “Third Party Financing” was activated/fired. Then the factors were set free to interact according to Eq. (1); here, the sigmoid function with \( \lambda = 1 \) was used as a threshold function. Once the FCM reaches equilibrium, the values may be interpreted quantitatively or qualitatively (Sadiq et al., 2004). For example, \( A^{(7)} = 0.98 \) implies that, after 7 iterations, Factor 1 is 98% of its maximum normalized value or qualitatively described Factor 1 is significantly active. Figure 4 demonstrates a scenario where only the factor “Third Party Financing” is activated. Since in all scenarios the system reached after seven iterations an equilibrium state (i.e. no change in activation levels is observed in two consecutive iterations) with almost similar steady state values of the factors, only the average final values are presented in this paper, see Table 1.
According to the results of the FCM simulations, the most critical factors influencing the energy service contracting market in Turkey are technological and economic developments with values over 0.95%. This indicates that the changes in external environment such as investments on technology, economic stability or macroeconomic equilibrium have significant impact on the market and the behavior of the firms that wish to implement energy efficiency projects for decreasing their energy costs. The results support the findings reported in the studies about the ESCO market in Turkey by Okay et al. (2008) and Okay and Akman (2010). Energy saving problem of the client firm, investment costs, technical experience, and energy costs are the next critical factors that influence the system of energy service contracting with values over 0.85%. In fact, when structural reforms are finished and financing mechanisms cleared the firms may solve their energy saving problems by investing in energy efficiency projects planned and implemented by technically experienced energy service companies, and thereby reduce their energy costs. Of course such decisions cannot be made independent of the firm’s energy policy (approximately 0.83%), but, energy service contracting will allow the client to reduce risk and concentrate attention on core activities (Sorrel, 2007). The results also imply that increasing energy consumption will make outsourcing indispensable. Although ESCOs project-financing mechanisms are not clear yet, the factors “Scope of the Contracts” and “Financing Difficulties” reached only a moderate significance in our simulations. This may be explained by Okay and Akman’s (2010) finding that ESCOs plan to finance energy projects with the help of EU and World Bank funds in the short run and with Turkish banks’ credits in the medium to long run. Finally, the low influence of the factor “Insourcing” (39.4%) on the energy services contracting system may imply for reliable results of the analysis.
4. Conclusion

This paper has explored and analyzed the critical factors influencing the energy service contracting market in Turkey. It was demonstrated that FCMs can be a useful tool for analyzing the complex system of energy service contracting by capturing experts’ understanding of the system. The method combines the capability of fuzzy logic to represent uncertain knowledge with dynamic modeling capabilities. The results provide basically soft evidence, which should further analyzed to make more detailed inferences about outsourcing decisions on energy efficiency projects.

5. References


Scope/Topic: Multi-Criteria Decision Making and Decision Analysis