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An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey☆

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ABSTRACT

Renewable energy resources (RER) are globally emerging as an energy generation alternative and latest research points out that these resources will have vital importance in the future. Limited reserves and negative environmental impacts of fossil fuels make investors to consider RER for sustainable development. In this study, a multi-criteria decision making (MCDM) approach is applied using the Decision Making Trial and Evaluation Laboratory Model (DEMATEL) technique, integrated with Analytic Network Process (ANP) for selecting the most appropriate RER in Turkey from an investor-focused perspective. The originality of the work comes from its ability to combine technical, economic, political and social attributes with a developed RER evaluation model and the effective and integrated framework it provides to select the most appropriate RER for Turkey for the first time using integrated DEMATEL and ANP approach.

1. Introduction

Electricity demand is increasing proportional to population growth, industrialization and urbanization across the world. Under business as usual scenarios, the demand for energy is expected to increase globally while fossil fuel sources are dwindling, energy prices increasing and environmental issues such as climate change are becoming more relevant. In parallel to these, as a developing country the energy need of Turkey has been rising continuously and energy shortages becoming a threat for next decades (Iskin et al., 2012; Kaya and Kahraman, 2010). The necessity to optimize the planning and the usage of energy resources has been an increasingly important issue (Xydis, 2013). With limited funds, governmental, public, private and institutional investors engage in a crucial role for future sustainable developments (Lee and Zhong, 2014). For these reasons, low cost, clean and secure energy supply is a common and fundamental issue for sustainable energy resources (Trappey et al., 2013). Under these circumstances, the selection of suitable energy generation alternatives becomes crucial, also for energy investments in Turkey. Development of energy sources in Turkey in a clean and sustainable way can be a viable option to eliminate the dependency on depleting fossil fuels and also to minimize the related negative environmental impacts, where renewable energy resources (RER) are being considered as an alternative.

One of the aims of this research is to identify relevant decision criteria and sub-criteria that are important to the RER selection problem from an investor's perspective. The other one is to propose an integrated framework that can be used to evaluate and choose the most appropriate RER for Turkey.

The use of multi criteria decision making (MCDM) techniques for energy investment planning, including RER, has since long attracted the interest of decision makers (DMs – experts). In the 1970s, it was more popular to treat energy problems as a search towards the most efficient supply options with an economical focus with minimum costs. Environmental awareness in the 1980s changed these views and opinions, as people realized the accompanying environmental and social considerations of energy investments, which gave way to the use of MCDM. When it comes to environmental and social issues, both qualitative and quantitative factors have to be considered in the decision process. Therefore, in literature, many attempts have been reported that incorporate MCDM approaches into the RER evaluation problem.

The model structure that is developed in this paper is a network hierarchy that can be used to evaluate various RER alternatives. For this purpose, the Analytic Network Process (ANP) (Saaty, 1996) technique is utilized, which can successfully handle dependencies among decision criteria. In order to extract the mutual relationships and strength of interdependencies among criteria, the Decision Making Trial and Evaluation Laboratory (DEMATEL) method (Gabus and Fontela, 1972) is used. In other

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words, the DEMATEL technique is introduced and combined with ANP in this study to make up for the equal weighting assumption of ANP and to explore the influential weights of the selected RER variables for forming an evaluation model. The proposed framework solves the previously encountered problems during the pair wise comparisons in ANP analysis and proposes a decision model that is able to deal with real world situations. In several studies, researchers have started to integrate these two techniques (such as; Büyüközkan and Öztürkcan, 2010; Chen et al., 2011; Hsu and Liou, 2013; Horng et al., 2014; Hu et al., 2014; Vujanović et al., 2012; Wu, 2008).

The main contributions of the paper are the development of an evaluation model from an investor perspective and the integration of DEMATEL and ANP methods for an effective RER selection problem. In literature, there are many studies which combine DEMATEL and ANP methods. In renewable energy sector, Azizi et al. (2014) integrated DEMATEL-ANP approaches in wind power plant selection. Nevertheless, there is no study so far in literature that combines these methods for the RER selection problem, nor in Turkey. This paper has originality not only for its evaluation methodology, but also for its use on a real case study in Turkey.

This article is organized in the following order. Section 2 introduces the theoretical background and the proposed model for the RER selection problem. Section 3 describes the methodology applied used in the calculation procedure. Section 4 includes an implementation of the introduced framework using a case study in Turkey and discussion of the obtained results. The final section concludes the paper.

2. Model development for effective RER selection

RER is defined as domestic resources which can provide energy with no or negligible emissions in terms of pollutants and greenhouse gases (Kahraman et al., 2010). RER (e.g. biomass, hydraulic, geothermal, solar and wind energy) are virtually inexhaustible and offer many environmental and economic benefits compared to traditional energy sources. In other words, each type of RER has its own special advantages that make it uniquely suited to certain applications in specific areas (Hepbasli, 2008). In literature RER is an important subject which attracts notable amount of interest in articles and research papers. Based on a detailed literature survey, it is seen that existing research discusses various different dimensions of RER. On top of these dimensions, discussions with experts can provide some improvements during the decision process. From an investor's perspective, DMs may encounter difficulties in selecting the most suitable alternative among many RER alternatives. Undoubtedly, for DMs, the selection criteria are one of the most important parts while constructing the decision model. Therefore, clearly defined criteria are needed for the alternatives to be compared from a specific point of view. Based on a detailed literature review and valuable contributions from industrial experts, this study attempts to develop an appropriate framework for selecting the most suitable RER alternative. This process starts with a review of the RER selection literature and then continues with the identification of the most frequently used criteria. For this process, information is gathered from research papers, several published investment project reports, conference papers and discussions with DMs. It has been observed that many authors have come up with numerous criteria in selecting the right RER selection alternative. DMs are provided with a model based on these literature-based criteria that they are welcomed to comment on, since DMs can provide insights for improving the decision process. For example, “compatibility with national energy political and legislative situation” was recommended by one of our experts and agreed on by the others. Ultimately, the evaluation criteria for RER are categorized under the following five main aspects: technical, economic, political, social and environmental.

In this criteria setup, *Technical aspects*, for instance, include *Efficiency* (C1) which measures how much useful energy can be obtained from an energy resource (Amer and Daim, 2011; Atmaca and Başar, 2012; Kaya and Kahraman, 2010; Talinli et al., 2010; Wang et al., 2009). *Reliability* (C2) is the ability to perform the system under intended or designed conditions. Also, it evaluates the technology of the renewable energy (Amer and Daim, 2011; Kahraman et al., 2010; Wang et al., 2009). *Resource availability* (C3) defines the availability of RER in a system (Amer and Daim, 2011; Aras et al., 2004; Chatzimouratidis and Pilavachi, 2009). The sub-criteria *Capacity of investment (*C4*)* refers to the role of technology related parameters such as geographical characteristics and production technology (Amer and Daim, 2011; Bürer and Wüstenhagen, 2009; Chatzimouratidis and Pilavachi, 2009; Iskin et al. 2012). *Technology maturity* (C5) indicates a specific technology's penetration in the energy mix at regional, national and international levels (Amer and Daim, 2011; Chatzimouratidis and Pilavachi, 2009). The last sub-criteria is *Technological innovation* (C6) which is the attitude towards a radical technology.

Economic aspects constitute one of the most important aspects of RER decision problems. It measures different sub-criteria, including *Investment cost* (C7), which is the total expenditure for establishing the energy technology including labor, equipment, installation, infrastructure etc. This aspect is the most used economic criterion to evaluate energy systems (Amer and Daim, 2011; Atmaca and Başar, 2012; Bürer and Wüstenhagen, 2009; Chatzimouratidis and Pilavachi, 2009; Cavallaroa and Cirolo, 2005; Daim et al., 2009; Erdoğmuş et al., 2006). *Operation and maintenance cost* (C8), another sub-criterion of Economical aspects, involves plant running cost, systems and equipments, personnel expenses and funds spent for energy products and services (Atmaca and Başar, 2012; Cavallaroa and Cirolo, 2005; Chatzimouratidis and Pilavachi, 2009; Erdoğmuş et al., 2006; Iskin et al., 2012; Kaya and Kahraman, 2010; Kahraman and Kaya, 2011; Leete et al., 2009; Önüt et al., 2008; Talinli et al., 2010; Wang et al.2009). *R&D cost* (C9) considers those expenses which occur on the research and development of technological innovations (Amer and Daim, 2011; Leete et al., 2009). The sub-criterion *Return on investment* (C10) judges the proposed renewable energy alternative economically and considers the project's worth on its investment. It can be measured by NPV or payback period methods (Kahraman and Kaya, 2010; Nigim et al., 2004; Wang et al. 2009). *Production cost* (C11) includes the cost of expected renewable energy resource (Amer and Daim, 2011; Dinica, 2012; Iskin et al., 2012).

Political aspects are another criterion that includes *Foreign dependency* (C12) which analyzes the integration of national energy policies with renewable energy alternatives and considers the dependency of countries to international legislations (Erdoğmuş et al., 2006; Goletsis et al., 2003; Iskin et al.,2012; Önüt et al., 2008). *Compatibility with political and legislative situation* (C13), under Political aspects, compares the suggested policy's consistency with the governmental policies. It includes government incentives, tendency of institutional actors, and policy of public information (Kahraman and Kaya, 2010). The sub-criterion *Compatibility with national energy policy* (C14) includes national energy policy related with renewable energy resources (Amer and Daim, 2011; Iskin et al.,2012; Talinli et al., 2010; Kahraman and Kaya, 2010). *Public policy and financial support* (C15) incorporates public incentives and financial accessibility by utilizing renewable energy resources (Bürer and Wüstenhagen 2009; Iskin et al., 2012).

Social aspects consist of social benefits, social acceptability and job creation sub-criteria. *Social benefits* (C16) encompass all benefits of renewable energy sources, for instance a social life and