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

Gülçin Büyüközkan*, Sezin Güleryüz

Galatasaray University, Industrial Engineering Department, 34357 Ortaköy, Istanbul, 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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* Corresponding author.
E-mail addresses: gulcin.buyukozkan@gmail.com (G. Büyüközkan), sezinguleryuz@yahoo.com (S. Güleryüz).

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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 subcriteria *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 income generation that would prevent people from emigrating from rural lands for public welfare (Amer and Daim,2011; Atmaca and Başar, 2012; Erdoğmuş et al., 2006;Iskin et al.,2012; Önüt et al., 2008; Wang et al.2009). *Social acceptability* (C17) is defined as people's approval and affirmative opinion on renewable energy sources (Amer and Daim, 2011; Cavallaroa and Cirolo, 200 5; Goletsis et al., 2003; Iskin et al., 2012; Kahraman and Kaya, 2010; Wang et al., 2009). *Job creation* (C18) corresponds to direct and indirect employment, as well as creation of new professional areas indirectly (Amer and Daim, 2011; Erdoğmuş et al., 2006; Iskin et al., 2012; Wang et al., 2009).

Under *environmental aspects,* one understands greenhouse emission, land use-requirement, impact on ecosystem and waste disposal. *Greenhouse emission* (C19) consists of greenhouse gases such as CO_2, NO_x etc. that mainly contribute to global warming, and some of them also lead to air pollution and acid rains (Amer and Daim, 2011; Cavallaroa and Cirolo, 2005; Iskin et al., 2012; Kahraman and Kaya, 2010; Kaya and Kahraman, 2011; Önüt et al., 2008; Talinli et al., 2010; Wang et al., 2009). The sub-criteria *Land use requirement* (C20) states that energy systems need space in order to generate energy where for energy investments cause strong demand for suitable land (Amer and Daim,2011; Iskin et al.,2012; Kaya and Kahraman, 2011; Kahraman and Kaya, 2010; Wang et al., 2009). The last factor is *Impact on ecosystem* (C21) which examines the potential risk to ecosystems. As an example, potential risks posed by wind turbines to avians (Amer and Daim, 2011; Dinica, 2012; Iskin et al., 2012; Kahraman and Kaya, 2010; Talinli et al., 2010) can be given.

3. Integrated DEMATEL & ANP methodology

3.1. Literature review of DEMATEL & ANP methodology

MCDM is one of the popular methods to deal with complicated problems that exhibit high uncertainty, clashing objectives, various interests and multiple perspectives (Pomerol and Barba-Romero, 2000). Besides, MCDM methodologies are effective in decision making, weighting and selecting the most appropriate alternatives.

As one of the many different MCDM methods, ANP introduced by Saaty (1996) is frequently used in literature. ANP is basically the extension of the well-known Analytic Hierarchy Process (AHP) (Saaty, 1980). AHP can simplify MCDM problems by assuming that criteria are independent from each other and hierarchical relationships among these criteria are one-way only (Karpak and Topcu, 2010; Tjader et al., 2014). In reality, however, they may have relationships among or within the groups of criteria. ANP is capable to deal with such complexities by incorporating interdependencies and feedback among criteria and alternatives in a decision model (Saaty, 1996). The main benefit of ANP over AHP is its ability to make predictions more accurate with better priority calculations in cases of networks with dependent criteria. It can handle the problems that cannot be modeled as a hierarchy because they consider dependence of higher level criteria in a hierarchy on lower level criteria (Pak, 2011). The ANP approach basically includes networks of influence with dependence and feedback. Each decision network consists of clusters, their elements and the links between elements. The usual AHP pair-wise comparison set uses a link between an element (the parent) and the elements it connects to in a given cluster (its children). In a system of dependencies, feedback among clusters and dependencies in the system tend to be depicted through these links. More specifically, links between elements within the same cluster indicate the inner dependencies of elements and links between a parent element in one cluster and its children in another cluster are defined as outer dependencies. The outer dependencies between two clusters in both directions is called feedback (Bayazit and Karpak, 2007; Karpak and Topcu, 2010).

In complex decision making problems, many elements can be related with each other directly or indirectly. In these situations, it becomes a challenge for a DM to avoid all other factors and to formulate an isolated evaluation between a single effect and a single factor (Chen and Chen, 2010). Moreover, strictly assuming a hierarchical structure which gives rise to linear activity with no dependence or feedback can cause problems that are different than the ones in non-hierarchical systems (Tzeng et al., 2007).

To deal with these issues, the DEMATEL method (Gabus and Fontela, 1972) can be used. DEMATEL can effectively build the structure of a relationships map with clear interrelations among sub-criteria for each criterion. It can also be applied to establish causal diagrams that are able to visualize the causal relationship of sub-systems (Büyüközkan and Çifçi, 2011). According to Gabus and Fontela (1972), DEMATEL can be utilized for measuring qualitative and factor-related aspects that are frequently faced in societal problems, as well as in other challenging problems that involve interactive man-model techniques. In literature, DEMATEL is adapted for different topics, including industrial planning, decision making, regional environmental assessment, sustainable development and other world problems (Huang et al., 2007; Rahman and Subramanian, 2012).

In recent literature, the DEMATEL and ANP techniques are integrated to determine the degree of dependencies among criteria and use these degrees to normalize the unweighted supermatrix in ANP (Hsu et al., 2012). When the relative weights of criteria are computed with the traditional ANP, the levels of their interdependencies are treated as reciprocal values. In the DEMATEL technique, the levels of these interdependencies do not have reciprocal values, which are similar to real world problems (Yang and Tzeng, 2011). To eliminate this weakness in ANP during calculating relative weights, calculating the total relation matrix within DEMATEL is more advantageous (Vujanovic et al., 2012).

The advantages of using the DEMATEL and ANP methods are well described by Pai (2014). DEMATEL is a useful method for analyzing cause-effect relationships, where it can quantitatively present the criteria and consider the related structural model. However, DEMATEL is not able to determine the weights of individual criteria, where ANP comes in handy. In cases where evaluation criteria are diverse and complicated, ANP can provide benefits in calculating criteria priorities and their relations. Both methods provide support in dealing with complex problems, as DMs can have a better insight about the problems to be solved, and also mutual relations among clusters of related factors. According to Horng et al. (2014), combining DEMATEL and ANP methods together can provide a helpful tool for identifying the critical attributes of policy implementation and calculating the weights of the business environment criteria.

The combined DEMATEL and ANP technique is frequently used in literature for solving MCDM problems. Table 2 summarizes some of these studies underlining their research scopes. This integrated structure can solve decision-making problems with different degrees of effects among criteria. Recently, Gölcük and Baykasoğlu (2016) analyzed the hybridization of DEMATEL and ANP techniques and reviewed the published papers in detail.

In related literature, those methods that integrate DEMATEL and ANP are applied in different business areas (banking, healthcare, management etc.). In the last two years, in particular, there are many studies that use DEMATEL-ANP methods together to overcome the individual weaknesses of using one method only, which are offset by the strength of the other method in real-life problems. However, in the renewable energy sector, such applications are very limited. As shown in Table 1, Azizi et al. (2014) utilized DEMATEL-ANP in wind power plant selection. There exist some studies which integrate DEMATEL and ANP methods in an

Table 1
Studies that combine DEMATEL and ANP.

Authors	Research scopes	Applied hybrid techniques
Liou et al. (2007)	Airline safety measurement	DEMATEL & ANP
Chen & Yu (2008)	Location selection for high-tech firms in Taiwan	DEMATEL & ANP
Wu (2008)	Selection of knowledge management strategies	DEMATEL & ANP
Tsai & Chou (2009)	Management system selection for sustainable development in SMEs	DEMATEL & ANP & Zero-One Goal Programming
Büyüközkan & Öztürkcan (2010)	Six sigma project selection	DEMATEL & ANP
Chen et al. (2010)	Evaluation of environment watershed plans	DEMATEL & ANP
Lin et al. (2010)	Evaluation of vehicle telematics system	DEMATEL & ANP & TOPSIS
Liou & Chuang (2010)	Outsourcing provider selection	DEMATEL & ANP & VIKOR
Tsai et al. (2010)	Sourcing decision of information technology functions	DEMATEL & ANP & Zero-One Goal Programming
Tseng (2010)	Evaluation of firm environmental knowledge management capability	DEMATEL & ANP & Fuzzy Set Theory
Ho et al. (2011)	Portfolio selection	DEMATEL & ANP & VIKOR
Lee et al. (2011)	Investment decision analysis	DEMATEL & ANP
Shen et al. (2011)	Technology selection	Fuzzy Delphi & DEMATEL & ANP
Chen et al. (2012)	Branding Taiwan's tourism	DEMATEL & ANP
Hsu et al. (2012)	Selection of best vendor in recycle industry	DEMATEL & ANP & VIKOR
Liu et al. (2012)	Implementation of o tourism policy management	DEMATEL & ANP & VIKOR
Liou (2012)	Selection of strategic alliance partners in the airline industry	DEMATEL & ANP & Fuzzy preference goal programming
Vujanovic´ et al. (2012)	Evaluation of vehicle fleet maintenance management indicators	DEMATEL & ANP
Wang (2012)	An appropriate interactive trade strategy evaluation	DEMATEL & ANP
Wang and Tzeng (2012)	Brand marketing	DEMATEL & ANP & VIKOR
Chiu et al. (2013)	Improving e-store businesses in order to satisfy customer needs	DEMATEL & ANP & VIKOR
Hsu and Liou (2013)	Selection of outsourcing providers in airline industry	DEMATEL & ANP
Lee and Lee (2013)	Evaluation of hospital service quality	DEMATEL & ANP & VIKOR
Lee (2013)	Merger and acquisition evaluation of Taiwanese banks	DEMATEL & ANP & VIKOR
Lu et al. (2013)	Evaluation and Improvement of RFID adoption in Taiwan's healthcare industry	DEMATEL & ANP & VIKOR
Tsai et al. (2013a, b)	Evaluation of corporate financing decisions	DEMATEL & ANP & Goal Programming
Tsai et al. (2013a,b)	Implementation of Enterprise Resource Planning	DEMATEL & ANP
Peng and Tzeng (2013)	Improving tourism destination competitiveness and supplier evaluation and improvement	DEMATEL & ANP & VIKOR & Fuzzy integral
Yang et al. (2013)	Assessment of security risk control for IT managers	DEMATEL & ANP & VIKOR
Zolfani and Ghadikolaei (2013)	Performance evaluation of private universities	DEMATEL & ANP & VIKOR &Balanced Scorecard
Azizi et al. (2014)	Wind power plant site selection	DEMATEL & ANP
Baykasoglu and Durmuşoglu (2014)	Assessment of private primary school	DEMATEL & ANP
Chen (2014)	Exploring key factors for procurement circulation	DEMATEL & ANP & VIKOR
Horng et al. (2014)	Evaluation of tourism and gourmet business environment	Fuzzy Delphi & DEMATEL & ANP
Hu et al. (2014)	Improving smart phone in order to satisfy customer needs	DEMATEL & ANP & VIKOR
Lee (2014)	Location selection of real estate brokerage services	DEMATEL & ANP & VIKOR
Liou et al. (2014)	Supplier selection	DEMATEL & ANP
Liu et al. (2014)	Material selection	DEMATEL & ANP & VIKOR
Pai (2014)	Analyzing consumer decisions to select micro-invasive aesthetic service providers	DEMATEL & ANP
Wang et al. (2014)	Six sigma project selection	DEMATEL & ANP & VIKOR
Zhou et al.(2014)	Safety management	DEMATEL & ANP
Abdollaahi et al. (2015)	Supplier selection	DEMATEL & ANP
Ahmadi et al. (2015)	Hospital information system adaption	DEMATEL & ANP
Fazli et al. (2015)	Customization of crude oil Supply chain risk management in Iran	DEMATEL & ANP
Govindan et al. (2016)	Evaluation of green manufacturing practices	DEMATEL & ANP & PROMETHEE
Jeng and Huang (2015)	Project portfolio selection	DEMATEL & ANP &DELPHI
Ju et al. (2015)	Selection of urban fire emergency alternative	DEMATEL &ANP & TL-TOPSIS
Kuo et al. (2015)	Supplier selection	DEMATEL & ANP & VIKOR
Lin (2015)	Determining product position	DEMATEL & ANP & VIKOR
Liou (2015)	Building a system for carbon reduction management	DEMATEL & ANP
Lu et al. (2015a)	Exploring mobile banking services for user behaviour	DEMATEL & ANP & VIKOR
Lu et al. (2015b)	Mobile commerce	DEMATEL & ANP & VIKOR
Nilashi et al. (2015)	Construction	DEMATEL & ANP
Pan and Nguyen (2015)	Customer satisfaction achievement	DEMATEL & ANP
Shen & Tzeng (2015)	Financial performance improvement of the banking industry	DEMATEL & ANP & VIKOR
Tuzkaya et al. (2015)	Emergency logistics canter location selection	DEMATEL & ANP
Adali and Isik (2016)	Third party logistics providers' selection	DEMATEL & ANP & Data Envelopment Analysis
Govindan et al. (2015)	Sustainable material selection	DEMATEL & ANP & TOPSIS
Huang et al. (2016)	Company's core competitiveness improvement	DEMATEL & ANP & VIKOR
Liou et al. (2016)	Selection of suppliers in green supply chain management	DEMATEL & ANP
Wu et al. (2016)	Disposal of dead pigs by pig farmers in China	DEMATEL & ANP

array of application areas. However, to the authors' best knowledge, no publication so far has attempted to combine DEMATEL and ANP for the RER selection problem. This study contributes to literature by filling this gap with a real case study.

There are several studies where MCDM techniques (such as Analytic Hierarchy Process (AHP), ANP, TOPSIS, ELECTRE, VIKOR) are used for RER selection both in online journals and theses. Pohekar and Ramachandran (2004) presented a review of MCDM and highlighted MCDM applications in the renewable energy area. Wang and colleagues (2009) reviewed MCDM literature of sustainable energy and classified it into criteria selection, criteria weighting, evaluation, and final aggregation. Abu-Taha (2011) classified the application area of MCDM in RER into the following four categories: renewable energy planning and policy, renewable energy evaluation and assessment, technology and project selection, and environmental. In a very recent study, Strantzali and Aravossis (2016) reviewed decision making methods in renewable energy investments. In contrast, our paper deals with the RER selection problem in which the investor has to select the best appropriate technology among a set of possible alternatives. In this perspective, Turkish literature has some applications with ANP. Ulutaş (2005) determined the appropriate RER for Turkey and the biomass alternative is found as a viable energy alternative. Kabak and Dağdeviren (2014) utilized ANP to prioritize RER alternative for Turkey and the hydropower alternative is selected to be suitable. Kuleli et al. (2015) presented a case study and used ANP to determine a renewable energy perspective for Turkey, again selecting hydropower as the frontrunner. Ishizaka et al. (2016) proposed a visualization method with AHP in order to help policy makers to gain insights into energy planning problems. As stated earlier, these recent studies have underlined the lack of applications that combine DEMATEL and ANP in RER selection, indicating a research gap in this area.

3.2. The computational steps of integrated DEMATEL and ANP framework

An overview of the integrated DEMATEL and ANP approaches is given in Fig. 1.

Briefly, the values are gathered with questionnaires. In cases of inner dependency, DEMATEL is employed. With these techniques, pair-wise comparisons are obtained from DEMATEL and the inner dependency is structured and represented with looped arcs.

Further calculations are carried out with ANP and used in the super matrix. The integrated DEMATEL and ANP methodology can be summarized in the following steps (Büyüközkan and Öztürkcan, 2010; Yeh and Huang, 2014; Tseng, 2009; Wu, 2008):

Step 1: Define the objective, criteria, sub-criteria and alternatives of the evaluation model: The evaluation criteria are obtained through literature survey, experts' knowledge and experience and other appropriate methods.

Step 2: Construct direct-relation matrix using DEMATEL: For comparing the relative importance degrees of components, a comparison scale is selected. The comparison scale consists of the following levels (Büyüközkan and Öztürkcan, 2010): no influence (0), low influence (1), medium influence (2), high influence (3) and very high influence (4). DMs are asked to compare the criteria pair-wise in terms of influence and direction. These evaluations are used for constructing a matrix with the dimensions of n x n, called the direct-relation matrix A. Here, a_{ij} stands for the degree to which the criteria i affects the criteria j.

Step 2.1: Normalize the direct-relation matrix: The direct-relation matrix A is used to calculate the normalized direct relation

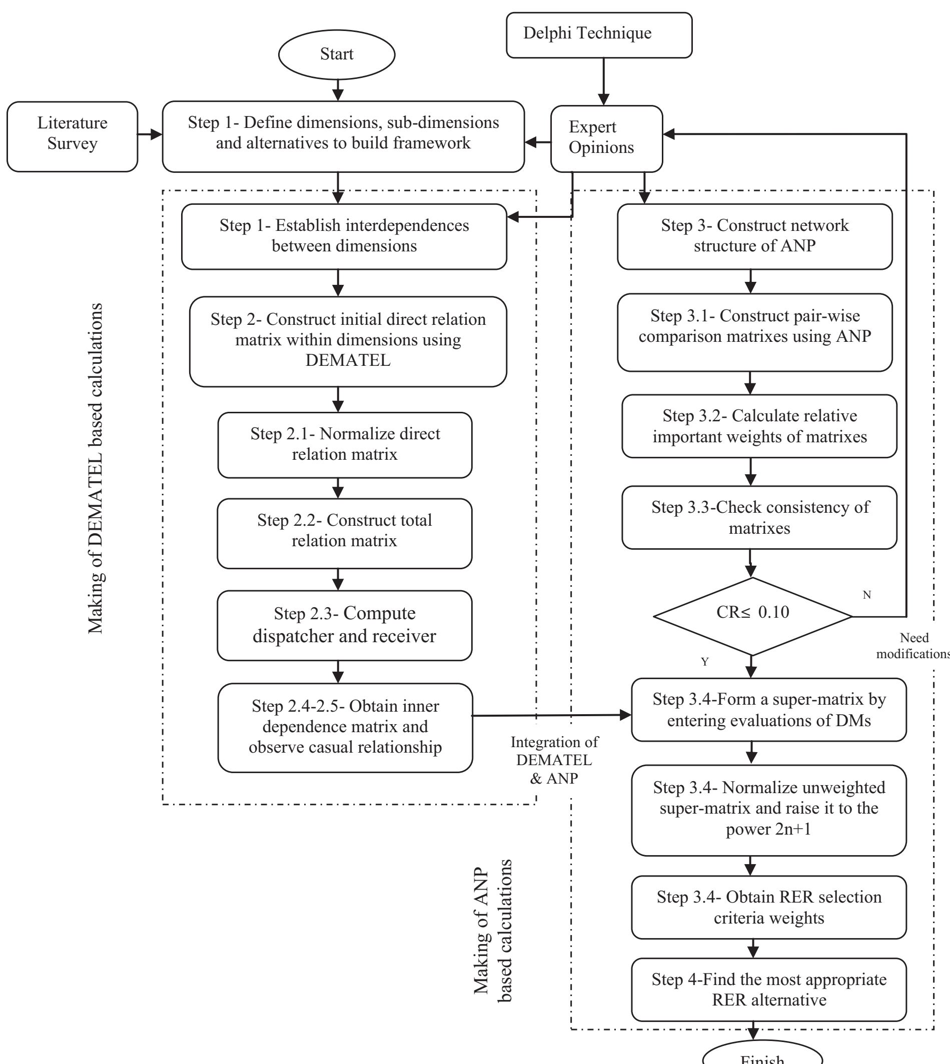

Fig. 1. A general view of RER evaluation framework.

matrix M, using the formulae (1) and (2).

$$M = k \times A \quad (1)$$

$$k=\min\left(\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max_{1\le j\le n}\sum_{i=1}^{n}|a_{ij}|}\right) i, j\epsilon\{1,2,3,\ldots n\} \quad (2)$$

***Step 2.2*:** Calculate the total-relation matrix: Once M, the normalized direct-relation matrix, is obtained, the following formula (3) is used to compute the total-relation matrix S, in which I is the identity matrix.

$$S = M+M^2 + M^3+\ldots= \sum_{i=1}^{\infty} M^i=M(I - M)^{-1} \quad (3)$$

***Step 2.3*:** Calculate dispatcher and receiver groups. The dispatcher is calculated from the D-R which have positive values and higher influence on one another.

They are assumed to exhibit higher priority and are called dispatcher groups, where R is the sum of columns and D is the sum of rows in matrix S, as indicated in the formulae (4)–(6). The other values with negative values of D-R receiving more influence from another are considered to have a lower priority and are called receiver groups. The value of D+R here shows the relation degree between each criterion with others. Those criteria that are exhibiting higher D+R values mean having more relationship with another and those having lower D+R values mean having less of a relationship with others.

$$S=\left[S_{ij}\right]_{nxn} i, j\epsilon\{1,2,3,\ldots n\} \quad (4)$$

$$D=\sum_{j-1}^{n} S_{ij} \quad (5)$$

$$R=\sum_{i=1}^{n} S_{ij} \quad (6)$$

***Step 2.4*:** Set a threshold value and construct the impact diagraph map: By mapping the dataset of the (D+R, D-R), the impact-diagraph map is obtained. Here, the horizontal axis indicates D+R and the vertical axis indicates D-R. In order to have an appropriate diagram, DMs must set an influence level threshold value. As the influence level in matrix S is higher than the threshold value, it can be converted into the impact-diagraph map.

***Step 2.5*:** Obtain the inner dependence matrix: The sum of each column in the total-relation matrix is equal to 1 by the normalization method.

***Step 3*:** Construct the network of the considered problem and evaluate the remaining nodes and alternatives using the ANP.

Step 3.1: Calculate the relative weights of criteria and establish a pair-wise comparison matrix: For the pair-wise comparisons, the 9-point priority measurement scale by Saaty (1980) is used. This scale from 1 to 9 represents pairs of equal importance (1), up to extreme inequality in importance (9). A DM can declare the relative dominance between each pair of elements verbally as: equally important, moderately more important, strongly more important, very strongly more important, and extremely more important. These judgments can be translated into numerical values of 1, 3, 5, 7, and 9 respectively. Values of 2, 4, 6 and 8 can be identified as intermediate values for comparisons between two successive points. Hence, reciprocals of these values are used for the corresponding transpose judgments.

***Step 3.2*:** Calculate the eigenvalues and eigenvectors of the comparison matrix. Suppose that there are N criteria $(C_1,.., C_i,.., C_n)$ and the pair-wise comparison matrix $A = a_{ij}$, where a_{ij} stands for the relative importance of criteria C_i and C_j. For all i and j, it is necessary that $a_{ii} = 1$ and $a_{ij}=1/a_{ji}$. The row vector average method, introduced by Saaty, is used to normalize the results, and the approximate weight W_i is calculated in formula (7) as follows:

$$W_i = \frac{\sum_{j=1}^{n}\left(\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}\right)}{n}, \forall\ i, j = 1, 2, \ldots, n \quad (7)$$

Here, the comparison matrix A completely responds to $a_{ik} = a_{ij}.\ a_{jk} \forall i,j,k$. The following formula (8) can be applied to obtain the approximate value of the largest eigenvalue λ_{max}.

$$AW = \lambda W \lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i} \quad (8)$$

***Step 3.3*:** Check consistency test: The consistency index (C.I) and consistency ratio (C.R) are used to estimate the consistency of the pair-wise comparisons via formulae (9) and (10).

$$C.\ I = \frac{\lambda_{max} - n}{n-1} \quad (9)$$

$$C.\ R = \frac{C.\ I}{R.\ I} \quad (10)$$

If the C.R is less than 0.1, the pair-wise comparisons are acceptable, otherwise they are not acceptable. R.I is the average index for randomly generated weights. When the number of levels in the hierarchy is n =2,…,8, R.I is 0.00; 0.58; 0.90; 1.12; 1.24; 1.32; 1.41, respectively.

***Step 3.4*:** Form a supermatrix by entering the vectors obtained from DEMATEL and ANP evaluations into the appropriate column: A supermatrix is defined as a partitioned matrix, in which every sub-matrix consists of relationships between two clusters. Local priority vectors are presented in the corresponding columns in the supermatrix. This supermatrix is first made stochastic (i.e. “weighted supermatrix”, where each column sums to 1). Following that, this “weighted supermatrix” is raised to its limiting powers until the weights converge to stable values, thus forming the “limit supermatrix”. By normalizing supermatrix blocks, eventual priorities are obtained (Büyüközkan and Çifçi, 2012).

***Step 4*:** Determine the most suitable alternative: The final priority values are found in the corresponding columns of the limit supermatrix. The weights are calculated for ranking the alternatives. Using the supermatrix, the alternative that has the highest overall priority value is selected.

4. Empirical case study – evaluation of RER in Turkey

Considering the complexity of energy related issues, many organizations make use of DMs instead of a single DM to accomplish the given tasks successfully. Group decision making (GDM) consists of a number of interacting individuals that provide their opinions to reach a common decision (Alonso et al., 2009; Büyüközkan and Feyzioğlu, 2004). Each DM may have his/her own motivations or objectives and may therefore see the decision-making process from another perspective. However, there exists a common motivation and interest in eventually reaching a final decision on selecting the “best” alternative(s) (Alonso et al., 2009). Therefore, in selecting the right alternative that helps in GDM process, the widely used Delphi method can be a trusted and accepted way for gathering data from respondents for their sector of expertise. This method relies on a group of experts who are expected to answer questionnaires in consecutive rounds. Such interviews with experts are helpful for providing new knowledge and new approach, as well as indicating the priority among

Table 2
The initial direct relation matrix for economic aspects.

	C7	*C8*	*C9*	*C10*	*C11*
C7	0	3	0	4	2
C8	3	0	2	4	4
C9	3	1	0	3	3
C10	1	1	1	0	1
C11	0	1	1	3	0

various criteria which are acquired from literature survey and interviews with experts. In this case study, the decision making process is carried out with the support of three DMs who have experience and expertise in RER. In this study, experts are asked to discuss the various motivations, considerations, and decisions that are related to selecting the most appropriate RER alternative. The DMs in this case have experience in investment. For ABC Company the DM1 is company manager, DM2 has a degree in finance and has experience in RER and DM3 is an engineer who is responsible for technical attributes and has been consulting the company for the last five years. The questionnaire is developed to assess the degree of importance of criteria. In decision making processes the criteria that were evaluated are ranked and the results are presented from an investor's perspective.

***Step 1*:** The objective, criteria, sub-criteria and alternatives of the decision making problem are determined in Section 2. In summary, the determined five criteria and a total of twenty-one sub-criteria are summarized as follows:

Technical aspects: Efficiency (C1), Reliability (C2), Resource availability (C3), Capacity of investment (C4), Technology maturity (C5), Technological innovation (C6).

Economic aspects: Investment cost (C7), Operation and maintenance cost (C8), R&D Cost (C9), Return on investment (C10), Production cost (C11).

Political aspects: Foreign dependency (C12), Compatibility with political legislative situation (C13), Compatibility with national energy policy objectives (C14), Public policy and financial support (C15).

Social aspects: Social benefits (C16), Social acceptability (C17), Job creation (C18).

Environmental aspects: Greenhouse emission (C19), Land use/requirement (C20), Impact on ecosystem (C21).

Finally, Wind (A1), Solar (A2), Geothermal (A3), Biomass (A4), and Hydraulic (A5) energy options are evaluated as alternatives in the decision model.

***Step 2*:** In the decision process, investors are expected to make pair-wise comparisons according to 4-leveled scale of DEMATEL.

***Step 2.1*:** The initial direct relation matrix for all criteria, which have inner-dependence, is produced. Not all matrices are shown here due to space limitations. As an example, the initial direct relation matrix of economic aspects which include C7, C8, C9, C10 and C11 is given in Table 2. Then, based on this initial direct relation matrix, the normalized matrix is calculated using the formulae (1) and (2).

The normalized direct relation matrix is shown in Table 3 as follows.

For instance, using the values provided in Table 1, the sums of columns and rows are calculated and the maximum value is obtained; k=1/14=0.071 and M=0.071*3=0.214.

***Step 2.2*:** Once M, the normalized direct-relation matrix, is obtained, the total-relation matrix S is found by using the formula (3) below. The total-relation matrix for economic aspects is given in Table 4, where D_i shows the row sum and R_i shows the column sum.

***Step 2.3*:** With the help of formulae (4)–(6), $D_i + R_i$ and D_i - R_i values are calculated and given in Table 3.

Table 3
The normalized direct relation matrix for economic aspects.

	C7	*C8*	*C9*	*C10*	*C11*
C7	0.000	**0.214**	0.000	0.286	0.143
C8	0.214	0.000	0.143	0.286	0.286
C9	0.214	0.071	0.000	0.214	0.214
C10	0.071	0.071	0.071	0.000	0.071
C11	0.000	0.071	0.071	0.214	0.000

Table 4
The total relation matrix for economic aspects.

	C7	*C8*	*C9*	*C10*	*C11*	D_i	D_i+R_i	D_i-R_i
C7	0.122	**0.305**	0.101	0.494	0.304	1.326	2.309	0.343
C8	0.344	0.167	0.243	0.586	0.476	1.815	2.744	0.887
C9	0.309	0.203	0.088	0.458	0.368	1.427	2.088	0.766
C10	0.132	0.129	0.111	0.133	0.160	0.664	2.653	−1.324
C11	0.075	0.125	0.119	0.317	0.095	0.731	2.135	−0.672
R_i	0.983	**0.929**	0.661	1.988	1.404			

***Step 2.4**:* In agreement with the computed data in the previous step, the impact diagram map for economic aspects is constructed by using data set ($D_i + R_i$, D_i - R_i). Here, the horizontal axis indicates $D_i + R_i$ and the vertical axis indicates D_i - R_i. The impact-diagraph map for the total relation of economic aspects is presented in Fig. 2. Here, $D_i + R_i$ is the sum of the relationships among all elements that shows the importance of each element in the overall relationship. When $D_i + R_i > 0$, it means that the elements affect the other elements to a greater impact than it is affected by them (and, visa versa)..

In order to have an appropriate diagram, DMs must set an influence level threshold. Here, the influence level in matrix S exceeds the threshold value, and can be converted into the impact-diagraph map. The threshold value for economic aspects is assumed to be 0.10. The results indicate that C7, C8 and C9 are dispatchers and C10 and C11 are receivers. From Table 3 it is seen that the operation and maintenance cost (C8) has the value of (*D–R=0.887)* and is regarded as the most important cause as it influences all the others with a high importance (*D+R*=2.744*)*. R&D Cost (C9) has (*D–R=0.766)* and is in cause group; however its (*D+R*=2.088*)* has the lowest importance.

***Step 2.5*:** According to the results obtained, it is seen that there is strong inner dependence among economical aspects criteria. It can also be seen from the converging $D_i + R_i$ values, which indicate the degree of relation and prove a strong inner dependence. The following criteria are examined in the same way and their inner dependencies are computed and shown in Fig. 3.

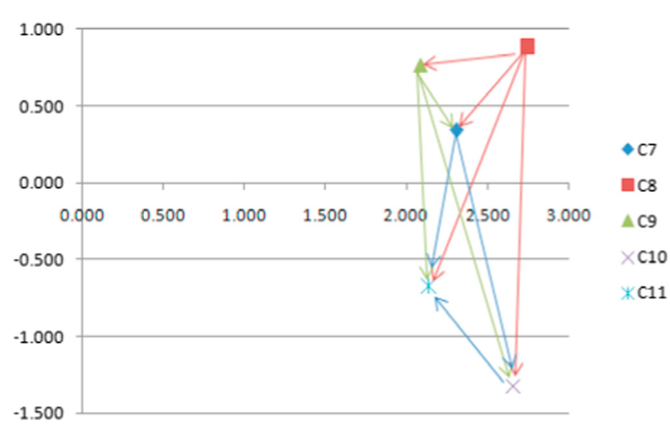

Fig. 2. The impact-diagraph map of the total relations for economic aspects.

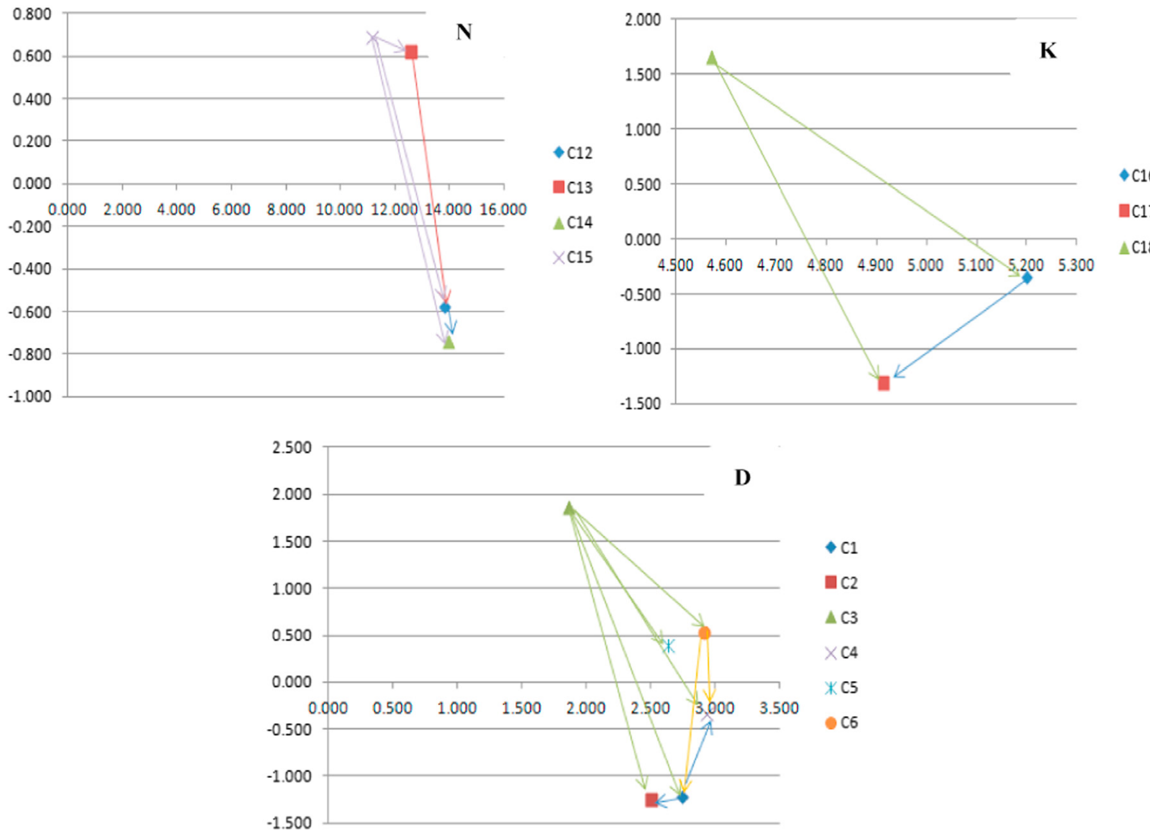

Fig. 3. The network relation maps of the remaining criteria and sub-criteria (N is the political aspects', K is the social aspects' and D is the technical aspects' inner dependencies).

Table 5
The inner dependences of economic aspects.

	C7	*C8*	*C9*	*C10*	*C11*
C7	0.124	**0.328**	0.152	0.249	0.217
C8	0.350	0.180	0.367	0.295	0.339
C9	0.315	0.219	0.133	0.231	0.262
C10	0.135	0.138	0.168	0.067	0.114
C11	0.076	0.135	0.180	0.160	0.067

Table 6
The general sub-matrix notation for supermatrix.

	Goal	*EA*	*TA*	*SA*	*PA*	*ENA*	*ALTS*
Goal	0	0	0	0	0	0	0
Economical aspects (EA)	A	E	B	0	M	0	0
Technical aspects (TA)	0	C	D	0	0	0	0
Social aspects (SA)	0	F	0	K	G	I	0
Political aspects (PA)	0	L	0	0	N	0	0
Environmental aspects (ENA)	0	0	0	H	0	0	0
ALTS	0	R	T	P	S	J	**I**

As an example, the inner dependence matrix of economic aspects is shown in Table 5. The value of 0.328 is calculated as 0.305/0.929=0.328 and the other values are calculated in the same way.

Step 3: Obtain the evaluation model: The notation for the sub-matrix can be seen in Table 6. Here, the relations for comparisons are shown with letters and "**I**" represents the identity matrix. From Table 6, D, E, K and N represent inner dependencies which are utilized in DEMATEL steps. The remaining feedback and outer dependencies are utilized in ANP steps. With these, the network structure of the evaluation model is constructed and summarized in Fig. 4. Here, ANP is used to find the weight of each criterion. The DMs can give judgments in numerical mode using Saaty's 1–9 scale. Discussions with experts are quite helpful in decision making process. It should be noted that it takes some time to fill in the questionnaire..

***Step 3.1*:** Due to space limitations, not all matrices are shown here. As an example economical aspects are presented. The pair-wise comparison matrix of economic aspects is shown in Table 7 as follows.

***Step 3.2*:** With the help of formulae (7) and (8), the relative weights are computed and is shown in Table 8.

The parameter λ_{max}, which is the maximum eigenvalue in pair-wise comparison matrix, is found to be 5.285.

***Step 3.3*:** In this step, the consistency of judgments is checked within the pair-wise comparison matrix. The results indicate the following; n=5, R.I =1.12, λ_{max}=5.285 and CI=0.07, hence with the help of formulae (9) and (10) C.R is calculated as 0.06. If CR ≤ 0.10, the degree of consistency is acceptable. In this case it gives meaningful results. Therefore the DMs judgments are sufficiently consistent enabling their use in the calculations in weighting estimates for various criteria.

***Step 3.4*:** The consistency ratios of matrices are checked and the priority vectors are provided in the corresponding columns of the supermatrix. Using the priorities calculated with DEMATEL (with bold values) and ANP, the initial supermatrix is found, as shown in Table 9. The weighted supermatrix is transformed first to be stochastic. After entering the normalized values into the supermatrix and completing the column stochastic, the supermatrix is then increased to sufficient large power until convergence occurs.

For this case application, the supermatrix is raised to its 7th power, and the resulting limit matrix is formed.

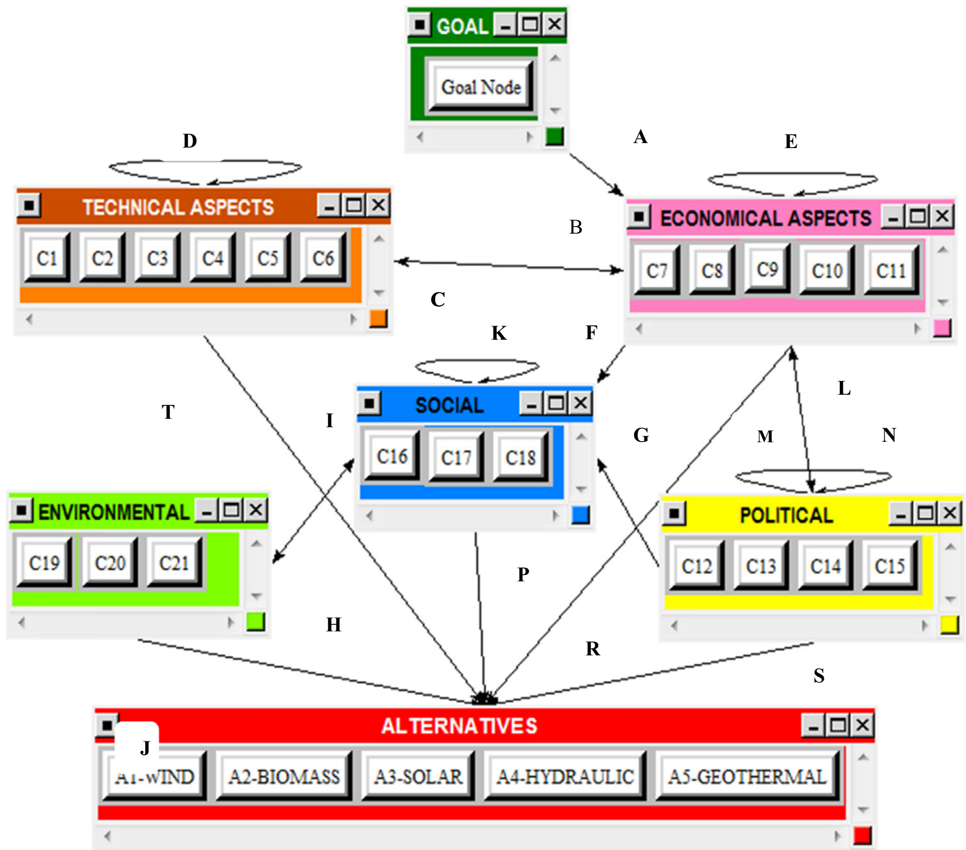

Fig. 4. Network structure of evaluation model.

Table 7
Economic aspects with respect to goal.

	C7	*C8*	*C9*	*C10*	*C11*
C7	1	3	3	3	3
C8	0.33	1	1	2	2
C9	0.33	1	1	1	3
C10	0.33	0.5	1	1	0.5
C11	0.33	0.5	0.33	2	1

Table 8
AW values of economic aspects with respect to goal.

	C7	*C8*	*C9*	*C10*	*C11*	*Weights*
C7	0.431	0.500	0.474	0.333	0.316	0.41
C8	0.142	0.167	0.158	0.222	0.211	0.18
C9	0.142	0.167	0.158	0.111	0.316	0.18
C10	0.142	0.083	0.158	0.111	0.053	0.11
C11	0.142	0.083	0.052	0.222	0.105	0.12

Step 4: The final ranking of RER is obtained as follows: A1 = 0.213; A2 = 0.199; A3 = 0.207; A4 = 0.197; A5 = 0.183. These results show that the first alternative which is wind energy has the largest score among all other alternatives, meaning that it should have priority in investment decisions.

5. Comparative validation

This section of the paper presents the comparison of the integrated DEMATEL-ANP outcome with ANP as well as a sensitivity analysis conducted on the variations of criteria weights.

Following the identification of the relationship structure using the DEMATEL methodology, in order to analyze the proposed integrated approach, only ANP method is used for calculating the priority of each alternative. With the help of Super Decisions software (www.superdecisions.com), pair-wise comparison matrices are formed and the alternatives are evaluated. According to the results given in Table 10, the rankings of the first two alternatives are the same, but are different for the remaining. This difference may originate from the integrated method that enables correlations and interdependency among various decision related criteria.

In order to evaluate the efficiency and accuracy of the DEMATEL-ANP hybrid model, Azizi et al. (2014) compared the results of ANP-DEMATEL with the results of ANP. Their findings showed a difference for the criteria weights between ANP and ANP-DEMATEL methods. They proposed that a comparison of priorities of the criteria from the questionnaires that are used to identify the most influential criteria, and models' results resulted in a better performance of the hybrid model.

A sensitivity analysis is applied to ensure the stability and the validity of our study's findings. The sensitivity analysis is conducted by changing the values of the evaluation criteria weights. In this analysis, C10 and C7 are selected because they have the largest weights with respect to other criteria and sub-criteria. As a first case (Case 1), the weight of C10 is changed from 0.334 to 0.500 and the weights of other sub-criteria of economic aspects node are modified proportionally. As a second case (Case 2), the weight of C7 is changed from 0.319 to 0.530. The sensitivity analysis results can be seen in Table 11.

It is interesting to remark that the final results are significantly different for the ANP method. In the new cases, solar energy is

Table 9
The unweighted supermatrix (The initial supermatrix of RER process-the bold values are).

	GOAL	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	A1	A2	A3	A4	A5
GOAL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C1	0.000	**0.059**	**0.096**	**0.064**	**0.101**	**0.127**	**0.122**	0.261	0.261	0.250	0.250	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2	0.000	**0.072**	**0.070**	**0.380**	**0.113**	**0.133**	**0.129**	0.111	0.111	0.107	0.107	0.107	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C3	0.000	**0.236**	**0.249**	**0.166**	**0.256**	**0.200**	**0.211**	0.324	0.324	0.311	0.311	0.311	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C4	0.000	**0.190**	**0.200**	**0.133**	**0.089**	**0.117**	**0.219**	0.111	0.111	0.107	0.107	0.107	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C5	0.000	**0.212**	**0.186**	**0.124**	**0.228**	**0.109**	**0.185**	0.097	0.097	0.093	0.093	0.093	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C6	0.000	**0.230**	**0.199**	**0.133**	**0.212**	**0.314**	**0.135**	0.097	0.097	0.133	0.133	0.133	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C7	0.319	0.319	0.349	0.319	0.319	0.349	0.319	**0.124**	**0.328**	**0.152**	**0.249**	**0.217**	0.319	0.349	0.349	0.349	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C8	0.096	0.096	0.105	0.096	0.096	0.105	0.096	**0.350**	**0.180**	**0.367**	**0.295**	**0.339**	0.096	0.105	0.105	0.105	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C9	0.081	0.081	0.089	0.081	0.081	0.089	0.081	**0.315**	**0.219**	**0.133**	**0.231**	**0.262**	0.081	0.089	0.089	0.089	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C10	0.334	0.334	0.365	0.334	0.334	0.365	0.334	**0.135**	**0.138**	**0.168**	**0.067**	**0.114**	0.334	0.365	0.365	0.365	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C11	0.170	0.170	0.093	0.170	0.170	0.093	0.170	**0.076**	**0.135**	**0.180**	**0.160**	**0.067**	0.170	0.093	0.093	0.093	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.400	0.400	0.400	0.400	0.400	**0.330**	**0.369**	**0.369**	**0.351**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.200	0.200	0.200	0.200	**0.196**	**0.167**	**0.201**	**0.212**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.200	0.200	0.200	0.200	**0.279**	**0.263**	**0.228**	**0.270**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.200	0.200	0.200	0.200	0.200	**0.196**	**0.201**	**0.201**	**0.167**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	**0.299**	**0.339**	**0.356**	0.333	0.333	0.333	0.000	0.000	0.000	0.000	0.000
C17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	**0.357**	**0.300**	**0.345**	0.333	0.333	0.333	0.000	0.000	0.000	0.000	0.000
C18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	**0.344**	**0.361**	**0.299**	0.333	0.333	0.333	0.000	0.000	0.000	0.000	0.000
C19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.333	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.333	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.333	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A1	0.000	0.231	0.200	0.250	0.203	0.206	0.306	0.155	0.200	0.138	0.164	0.200	0.125	0.200	0.200	0.266	0.222	0.331	0.167	0.315	0.233	0.219	1.000	0.000	0.000	0.000	0.000
A2	0.000	0.198	0.200	0.142	0.102	0.109	0.091	0.291	0.200	0.260	0.186	0.200	0.250	0.200	0.200	0.145	0.222	0.125	0.333	0.083	0.085	0.219	0.000	1.000	0.000	0.000	0.000
A3	0.000	0.198	0.200	0.309	0.203	0.368	0.342	0.126	0.200	0.082	0.115	0.200	0.125	0.200	0.200	0.266	0.222	0.331	0.167	0.262	0.233	0.219	0.000	0.000	1.000	0.000	0.000
A4	0.000	0.176	0.200	0.132	0.384	0.109	0.171	0.334	0.200	0.260	0.349	0.200	0.250	0.200	0.200	0.106	0.111	0.067	0.167	0.157	0.233	0.102	0.000	0.000	0.000	1.000	0.000
A5	0.000	0.198	0.200	0.167	0.108	0.206	0.091	0.095	0.200	0.260	0.186	0.200	0.250	0.200	0.200	0.217	0.222	0.147	0.167	0.183	0.216	0.239	0.000	0.000	0.000	0.000	1.000

Table 10
Ranking of RER alternatives.

Applied methodologies	*Wind*	*Solar*	*Biomass*	*Geothermal*	*Hydraulic*
Integrated DEMATEL and ANP	0.213 (1)	0.207 (2)	0.199 (3)	0.183 (5)	0.197 (4)
ANP	0.240 (1)	0.233 (2)	0.186 (4)	0.191 (3)	0.150 (5)

Table 11
Sensitivity analysis cases and related results.

Applied methodologies	*Wind*	*Solar*	*Biomass*	*Geothermal*	*Hydraulic*
ANP (Case 1)	0.260 (2)	0.310 (1)	0.106 (5)	0.174 (3)	0.149 (4)
Integrated DEMATEL-ANP (Case 1)	0.213 (1)	0.206 (2)	0.200 (3)	0.185 (5)	0.196 (4)
ANP (Case 2)	0.262 (2)	0.271 (1)	0.167 (4)	0.198 (3)	0.102 (5)
Integrated DEMATEL-ANP (Case 2)	0.212 (1)	0.206 (2)	0.203 (3)	0.179 (5)	0.199 (4)

ranked as the first alternative. On the other hand, the results of our DEMATEL-ANP method seem to be intact with these modifications. The ranking of the alternatives remains the same in each case. In sum, the given examples assist us to realize the usefulness of using integrated DEMATEL-ANP methodology for an effective evaluation process.

As a summary, related to the ANP method, even small alterations in the evaluations could radically change the solutions. This is really an undesirable consequence for a DM since it creates an extreme pressure during the evaluation process. However, the combined DEMATEL-ANP methodology assists us to reflect more rigorously the reality and to have more robust evaluations.

6. Managerial implications and discussions

The proposed integrated evaluation framework can be used by energy investors for a more effective assessment of RER alternatives. Considering that RER assessment is a multi-dimensional problem by its nature, a single model is not able to explain the whole evaluation process for deciding on the most appropriate RER. To address this gap, our study combines technical, economical, political, social and environmental attributes in a developed RER evaluation model.

The reason for integrating DEMATEL in this feedback model is its strength in evaluating complex interrelationships among various aspects and sub-criteria, as well as in handling inner dependencies (Büyüközkan and Öztürkcan; 2010; Wu, 2008). To check its validity, the model is assessed by experts to gain better understanding of its advantages and drawbacks.

This developed evaluation framework can help managers and researchers in reaching useful judgments, gaining research insights and working on practical applications through the examination of five aspects (or criteria) and twenty-one sub-criteria. Thus, the model does not simply follow a traditional linear hierarchical approach and can provide managers with a valuable tool in gathering information in complicated causal relationships that can be useful in decision making.

Obtaining influential weights with DEMATEL reveals the arithmetic process based on sub-dimensions. The relationships among Efficiency (C1), Reliability (C2), Resource availability (C3), Capacity of investment (C4), Technology maturity (C5) and Technological innovation (C6) are considered. Resource availability (C3) with (D-R=1.729) is regarded as the most important one among these six sub-criteria and it influences all the others with low importance ($D+R$=2.228). The Technological innovation (C6) has (D - R=0.570) and is in cause group with its ($D+R$=3.069). Therefore, investors should focus on Resource availability and Technological innovation criteria. The relationships among Social aspects including Social benefits (C16), Social acceptability (C17), Job creation (C18) are determined and Social benefits (D - R=0.762) is regarded to be the most important one among these three. This criterion encompasses all societal benefits from RER and represents social progress in local community, and should therefore be considered by investors. Within the Political aspects, Foreign dependency (C12) is regarded as credible among Compatibility with political legislative situation (C13), Compatibility with national energy policy objectives (C14), Public policy and financial support (C15). According to these results, investors should analyze the integration of national renewable energy policies and consider alternatives which can make the country less dependent on imported energy resources.

The RER selection model provided in this study can be used overall world. There are some differences that users should keep in mind when applying this model: the level of importance of the criteria could vary in different situations. This study can be useful to researchers for better understanding the RER selection problem theoretically, as well as to investors for better designing satisfying RER evaluation systems.

In recent years, articles involving the DEMATEL method in conjunction with ANP are published in increasing numbers. Many studies (as given in Table 1 of our paper) underline the necessity and benefits of applying integrated DEMATEL and ANP methods. For instance, Shen and Tzeng (2015) classified the advantages of DEMATEL based ANP (DANP) as: "DANP adjust the weights for dimensions to extend the equal-weight assumption of the original ANP method." and "The DEMATEL analysis supports to identify the cause-effect relationship among the core attributes which may support decision makers to plan for improvements".

Recently, Gölcük and Baykasoğlu (2016) deeply analyzed ANP and also other hybrid methodologies that are built upon it, and clearly highlighted why DEMATEL based ANP has some further theoretical and practical characteristics that make it favorable to the traditional ANP. These qualities are briefly exposed in the following items:

Identification of criteria structure: The criteria structure must be known before applying ANP. Despite its strong mathematical foundations, ANP methodology does not include any systematic approach to identify criteria and associated clusters, and their interdependencies. For that reason, DEMATEL is widely used to grasp the network relationship map of the problem in the literature.

Pair-wise comparisons and survey questions: In general, pairwise comparisons are cognitively demanding. Moreover, identification of the priorities for inner dependencies entails especially some ambiguous questions to be answered. To overcome this difficulty, inner dependency-related priorities in the supermatrix are calculated by DEMATEL. Since DEMATEL method is based on the cause-effect type relationships, constructing direct relation matrix is much more practical.

Unequal importance of clusters: Clusters of criteria are assumed to be equally important in traditional ANP. As this cannot always be true in general, influences among clusters can be obtained with DEMATEL. Moreover, influence degrees among clusters can be used to weight the unweighted supermatrix, which leads to weighted supermatrix. All columns of the weighted supermatrix are sum to unity so that it can be raised to large powers to obtain steady state weights.

Moreover, to evaluate the efficiency and accuracy of the

DEMATEL-ANP hybrid model, Azizi et al. (2014) compared also the results of ANP-DEMATEL and ANP methods. They found that the weights and priorities of the criteria differ significantly between ANP and ANP-DEMATEL. They indicated that a comparison of priorities of the criteria from the questionnaires, used to identify the most influential criteria, and models' results in emphasized the better performance of the hybrid model.

7. Conclusions

Renewable energy has become a priority for Turkish policy makers over the past decade, particularly due to its role in expanding power generation and diversifying the energy supply mix in an environmentally sustainable way. The objective of this paper is to evaluate available RER alternatives and to select the most suitable energy option for Turkey from an investor perspective. In decision and evaluation processes, there are many factors which include subjective and qualitative judgments and require the consideration of different complex factors. In such processes, MCDM methods can be effectively employed to choose the most suitable energy option correctly.

After performing a detailed literature survey and considering expert opinions, an evaluation model is developed. An MCDM approach based on DEMATEL integrated with ANP methodology is considered for selecting the most appropriate RER in Turkey from investor-focused perspective. An empirical case study is carried out in order to validate how effective the proposed model performs. The obtained results confirm that the proposed model can help investors and practitioners in improving their decision processes, particularly in cases where there are many inter-related criteria.

This study contributes to literature by extending practical applications of both ANP and DEMATEL in the RER evaluation field. The ANP method offers a more accurate analysis by handling interdependent relationships, however it takes more time. It should be emphasized that additional interdependency relationships geometrically increase the number of pair-wise comparison matrices. DEMATEL can be used for dealing with the inner dependencies of criteria. It can also generate more valuable information for decision making. For these reasons, combining ANP and DEMATEL provide successful results in reaching strategic decisions.

It should be emphasized that there is no similar research on the Turkish energy market using these methodologies. Therefore, this study fills the gap by using an integrated framework in this specific application area.

As a future work, the presented evaluation framework can be adapted to different RER evaluation projects.

It is possible for a DM not having sufficient expertise, time, motivation or knowledge on a topic, which can prevent the DM to perfectly state the degree of his or her preference between the available alternatives. These kinds of evaluation constraints can be dealt with incomplete preference relations in GDM. Different aggregation operators may also be used which can increase the effectiveness of the evaluation process. In our future studies, we aim to investigate these research dimensions.

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