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Multi-expert wind energy technology selection using interval-valued intuitionistic fuzzy sets

Sezi Cevik Onar [a], Basar Oztaysi [a], İrem Otay [b], Cengiz Kahraman [a, *]

[a] Department of Industrial Engineering, Istanbul Technical University, Macka, 34367, Istanbul, Turkey
[b] Department of Management Engineering, Istanbul Technical University, Macka, 34367, Istanbul, Turkey

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ABSTRACT

Wind energy has been one of the popular and important energy sources since it is a clean, safe, affordable, and bountiful energy source present in nature. The evaluation of wind energy investments requires a large number of tangible and intangible criteria which may conflict with each other. Our study concentrates on the evaluation of wind energy investments and aims to select the appropriate wind energy technology to help investors. The problem is constructed as a multi-expert multicriteria decision making problem. To deal with vagueness, ambiguity and subjectivity in the human evaluation processes, an IVIF (interval-valued intuitionistic fuzzy) approach is proposed. IVIF sets can better handle hesitancy and uncertainty in defining membership functions. Our approach realizes the overall performance measurement of wind energy technology alternatives through the aggregation of IVIF pairwise comparison matrices and calculation of score judgment and possibility degree matrices. A sensitivity analysis is also conducted to assess the robustness of the results obtained from the model. The comparative results show that the proposed method produces a consistent ranking among the alternative technologies and the sensitivity analysis indicates that this ranking is sufficiently robust to invest in the first ranked alternative.

1. Introduction

RE (renewable energy) is one of the areas drawing attention of researchers as well as practitioners due to many reasons, e.g. rising awareness of the environmental issues covering especially global warming and emission of GHG (greenhouse gases), security of supplying fossil fuels and increasing price trend of the fossil fuels [2,20].

Especially in the last decades, the global wind industry has demonstrated a dramatic increase [19,39]. Europe with 63,889 MW of installation capacity, USA with 25,408 MW of capacity, and Asia (mainly China, India, and Japan) with 19,524 MW of power are the top-tier markets with regard to wind power generation in 2009. Globally 41.24 GW of new wind power is installed alone in 2011 [39]. Today, wind energy accounts for almost 36 percent of total generated renewable energy worldwide. The world's total installed capacity was 238.126 GW in 2011 while it reached 318.105 GW in 2013 [23]. In Fig. 1, newly installed capacity (MW) of top-10 countries for wind power/energy is illustrated for the year 2014 [58].

In Fig. 2, wind energy market forecasts (GW) by regions are presented for the years between 2014 and 2019 [58]. As it is seen from Fig. 2, Asia is by far the leading wind energy market followed by Europe whereas Middle East and Africa is the smallest wind energy market.

In Turkey, wind power has been among the cheapest electricity sources since the production cost of wind energy was between 0.5 and 0.55 Euros/kWh in 2009 [19]. Turkey produces 25% of electricity from renewables, and projects to increase electricity generation from renewables to 30% and to reach 20 GW installation capacity by 2023. The highest wind power is in the north-west (730.65 MW), west (786.2 MW) and south-west (372.5 MW) shores of Turkey with 10 m/s average speed [60]. In 2008, the installed wind capacity climbed to 433 MW [15]. The biggest wind energy plant constructed in 2012 has around 140 MW capacity [3]. According to the reports of TWEA (Turkish Wind Energy Association), in the first quarter of 2012, there were around 50 wind farms with 1803 MW capacity, operating in the country. By the end of 2015, the Turkish Wind Energy Association targets to reach 5000 MW from wind power. For 2023, the installed capacity of wind energy in Turkey is expected to be 20,000 MW [15].

* Corresponding author.
E-mail address: kahramanc@itu.edu.tr (C. Kahraman).

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In the literature, there are many studies conducted on wind energy/power, wind turbine, and wind farms. In this section, the latest studies are briefly summarized. Shamshirband et al. [43–45] used ANFIS (adaptive neuro-fuzzy inference system) to predict the wind speed probability density dispersion, the wind turbine wake added turbulence and the wind turbine wake power deficit. Wang and Xiong [47] forecasted capacity of daily wind speed by proposing a hybrid model composed of the ARIMA (autoregressive integrated moving average) model, artificial neural networks, and fuzzy time series. Wang and Xiong [40] used lexicographic order and ELECTRE-TRI methods for the solution of onshore wind farm location selection problem in Spain. Sanchez-Lozano et al. [16] analyzed market equilibrium for offshore wind industry, and calculated energy yield, lifetime project profitability and levelized cost of electricity for a wind farm in the German North Sea. Ederer [56] developed a multiobjective model for the distribution networks of wind turbines, hydro turbines, and fuel cells. The model aiming to minimize total electrical energy costs, the electrical energy losses, total emissions produced, and voltage deviations, was solved by using modified bee swarm optimization. Zare et al. [42] presented a cyclic inhomogeneous Markov process for wind turbine power production in Portugal. A constrained optimization model was suggested for solving the problem.Scholz et al. [51] solved a wind farm project selection problem by using IFC (intuitionistic fuzzy Choquet) operator and GIFOGA (generalized intuitionistic fuzzy ordered geometric averaging) operator. Wu et al. [50] employed analytic hierarchy process for site selection problem of solar–wind hybrid power station using a wide variety of criteria such as accessibility, economy and risks. Petkovic et al. [36] used ANFIS in order to predict the annual probability density distribution of wind speed. Nikolic et al. [34] also used ANFIS to predict the wake wind speed deficit and power deficit ratio in wind farms. Suganthi et al. [46] reviewed the renewable energy literature for the studies applying fuzzy logic. The authors indicated that there were high numbers of studies employing fuzzy models in site selection and installation of wind farms as well as other renewable energy sources. They also emphasized that fuzzy based models provided more realistic results. Kayal and Chanda [26] proposed an optimization model for solving location and site selection problem for electrical generation from solar and wind energy. In the study, a model composed of multiple objectives such as minimization of payback year, reduction of power loss and voltage stability level is solved by a particle swarm optimization technique. Betakova et al. [8] conducted a study for planning placement of wind turbines by considering distances and numbers of turbines and visual quality of landscape. Al-Yahyai and Charabi [1] analyzed land suitability for wind energy by predicting weather conditions and by using a fuzzy multicriteria method.

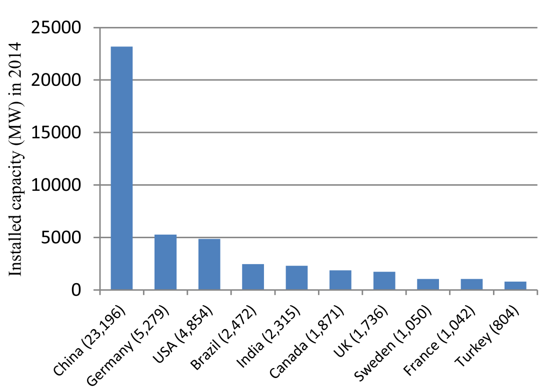

Fig. 1. New installed capacity of top-10 countries in 2014.

Our study focuses on wind energy technology selection decision which is a typical multicriteria problem entailing to consider a variety of quantitative and qualitative criteria in the fuzzy decision making process. In classical multicriteria decision making methods, the judgments of decision makers are represented by exact numbers. Nevertheless, in the real industrial applications, people are more likely to prefer making linguistic evaluations instead of using exact numerical values because of imprecise data, lack of information and vagueness in data. In order to solve the ambiguity, vagueness, subjectivity in the human judgments; the fuzzy set theory was introduced by Ref. [55]. In this study, the wind energy technology selection problem is solved under fuzzy environment by considering uncertainties and ambiguities in the decision making processes.

In the literature, the frequently used methods for the evaluation of wind energy are ELECTRE, AHP (Analytic Hierarchy Process), ANP (Analytic Network Process), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje), Axiomatic Design, and Choquet Integral. The crisp applications of these methods can not employ the vague evaluations, which humans generally prefer, while their fuzzy extensions can do it. However, most of these fuzzy extensions utilize type-1 fuzzy membership functions and apply a defuzzification process in the very early stages. Recently developed hesitant and intuitionistic fuzzy sets let a detailed definition of fuzzy membership functions and a better expression of linguistic evaluations to be incorporated in to the method.

Intuitionistic fuzzy sets extend the ordinary fuzzy sets by an additional degree, which is called the degree of uncertainty [37]. An IFS (intuitionistic fuzzy set) is associated with the membership function, the non-membership function and the hesitancy function. In Ref. [7] introduced IVIFS (interval-valued intuitionistic fuzzy sets), which are a generalization of both interval valued fuzzy sets and intuitionistic fuzzy sets. In their study, a membership function and a non-membership function are defined by employing interval values rather than a single real number. According to some authors, IVIFS is more powerful and flexible tool to cope with vagueness and uncertainty than the other types of IFS [9,13].

Usage of IVIFS in fuzzy multicriteria decision making literature is very popular. Zhang and Yu. [57] developed an optimization model employing interval-valued IFSs (intuitionistic fuzzy sets) with Cross-entropy and TOPSIS. Chen et al. [12] proposed a new ranking method for interval-valued intuitionistic fuzzy sets. Jin et al. [21] used interval-valued intuitionistic fuzzy sets with fuzzy continuous weighted entropy and implemented it for a group decision making process. Recently many authors have concentrated on aggregation methods of interval-valued intuitionistic fuzzy sets. Aggregation operators have been developed to synthesize interval-valued intuitionistic preference information. Xu and Chen [52,54,13] presented aggregation operators, namely IIFWA (interval-valued intuitionistic fuzzy weighted arithmetic aggregation), the IIFOWA (interval-valued intuitionistic fuzzy ordered weighted aggregation), and the IIFHA (interval-valued intuitionistic fuzzy

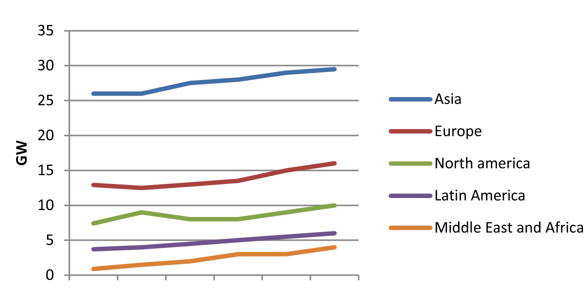

Fig. 2. Wind energy market forecasts (GW) by regions between 2014 and 2019.