Article

Risk Evaluation Model of Wind Energy Investment Projects Using Modified Fuzzy Group Decision-making and Monte Carlo Simulation

Arthaniti: Journal of Economic Theory and Practice
22(1) 7–33, 2023

DOI: 10.1177/0976747920963222
journals.sagepub.com/home/ath
Sage

Abdolmajid Erfani[1] and Mehdi Tavakolan[2]

Abstract

The recent increasing trend of investments in wind energy projects to support sustainable development requires an appropriate risk evaluation model to ensure the success of these projects. Early studies focus on opinion and discussion from subject matter experts. However, the expertise level in the subject is varied, and evaluation without considering expert competency can cause biased results. On the other hand, most of the project cost estimation models do not consider uncertainty in all cash flow parameters. In response, this article proposes a model that evaluates risks in wind energy investment projects by considering the knowledge and background of experts. Then, an integrated model of risk evaluation and cost estimation is developed. The model consists of three main stages: risk identification based on a systematic literature review (SLR); risk analysis phase 1 based on a modified fuzzy group decision-making; and risk analysis phase 2 based on a Monte Carlo simulation method. The main advantages of the proposed model are: (a) providing a comprehensive risk identification in wind energy investment projects; (b) using a modified fuzzy model to improve the risk assessment process by considering the expert competency in wind energy projects; and (c) establishing an integrated model to evaluate the cash flow of the investment. A wind farm in the Middle East is selected as the case study to examine the usability and practicality of the proposed model. The results show that the most important risks are 'change in regulation and policy', 'dependency on the international market for importing raw materials' and 'market competitiveness'. On the other hand, the financial assessment under uncertainty shows that the profitability of the investment can be varied, and it emphasises the impor-

[1] Graduate Research Assistant, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD, USA
[2] School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran

Corresponding author:
Mehdi Tavakolan, School of Civil Engineering, College of Engineering, University of Tehran, Tehran 90405-4414, Iran.

tance of an appropriate risk management process to guarantee the success of the investment.

Keywords

Wind energy, fuzzy logic, risk assessment, Monte Carlo simulation, sustainable development

JEL: Q42, P48, G32, O13

1. Introduction

Global investment in renewable energy (RE) projects has increased significantly over the last decade. (Bennett et al., 2020; Nematollahi et al., 2016). According to the renewable global status report (REN21, 2019), a total of 181 GW of RE projects were added in 2018, which caused about an 8 per cent increase in the share of RE sources to 2017. Developing countries provided half of investment in these projects in the world in 2018. However, the situation of developing Middle East countries is different. Middle East countries are the largest producers and exporters of oil and natural gas in the world (OPEC, 2018), which affects their economic preference (Sa'eed, 2015). There was little interest in investing and developing RE projects in these countries. This trend has been changing recently, and investments in RE projects have grown steadily (Zarnegar, 2018).

Various reasons have caused the increasing trend in developing RE projects. First, the low energy prices and low efficiency have resulted in over-consumption of energy (Afsharzade et al., 2016). High dependency on conventional fuels will be a huge threat for the future. On the other hand, one of the main sources of producing greenhouse gases in the world is the power generation sector (Ghoshal & Bhattacharyya, 2008; Mollahosseini et al., 2017; Razmjoo & Davarpanah, 2019). Because of the availability and low price of fossil fuels, natural gas and crude oil are considered as the main fuels of power plants in these countries. Therefore, environmental concerns, especially carbon dioxide (CO_2) emissions and climate change, are challenging issues for their governments (Ghosh, 2018; Kachoee et al., 2018; Shahsavari & Akbari, 2018). Finally, in the field of developing RE projects, beyond the technical issues, the potential of natural resources such as solar radiation and wind profile are crucial (Aslani et al., 2012). In this regard, the governments' main policy to solve these problems and reduce CO_2 emissions is developing RE power plants (Hosseini et al., 2013).

Despite the strong potential of renewable energies and the obvious reasons to develop RE investment projects in the Middle East, only about 1 per cent of the required energy is supplied from RE sources (Tavana et al., 2019). Therefore, the policymakers and governments of these countries place the priority on developing RE projects (Gorjian et al., 2019).

The most challenging issue faced by investors is that wind energy projects investment, which can even lead to the failure of these projects (Liu & Zeng, 2017). Different risks like changes in laws and supportive policies of the government, consumption market and social and environmental issues affect these projects; therefore, investors must have enough awareness of these risks (Turner et al., 2013). Early studies in the construction industry (Abdelgawad & Fayek, 2010; El-sayegh & Mansour, 2015) focus on opinions from and discussions among subject matter experts. However, the expertise level in the subject is varied, and evaluation without considering expert competency can cause biased results (Monzer et al., 2019). To fill this gap, this article proposes a combined fuzzy group decision-making and Monte Carlo simulation that considers the level of expertise in the subject. The proposed model not only identifies the risks and responds to these risks based on their level of importance but also proposes a financial model based on the evaluated risks. The results of the study can be instrumental for investors to identify the challenges for their investment and then choose the possible ways to answer these challenges in the future. Also, the research findings are expected to help governments shape their future policy to increase the participation of the private sector in wind energy investment projects.

II. Literature Review

Risk management in RE investment projects includes three important phases: risk identification, risk evaluation and risk response. This process is completed in order to increase the possibility of occurrence of positive risks and their impacts or decrease the possibility of occurrence of negative risks and their impacts (Guerrero-Liquet et al., 2016). On the other hand, a large amount of investments in this kind of project cause the necessity of an appropriate risk management process (Balatbat et al., 2012; Gass et al., 2011; Liu & Zeng, 2017). Therefore, various studies deal with the risk management of renewable energy projects in the literature. For instance, Gatzert and Kosub (2016) identified critical risk factors affecting wind energy projects. They classified the risks under seven main groups: 'business', 'construction', 'operation', 'legal', 'market', 'counterparty' and 'political' risks. Finally, they proposed certain responses to the identified risks. They emphasised that 'legal and regulatory' and 'business and market' risks are the major barriers for onshore and offshore wind farm construction in Europe. However, the lack of a quantitative model to prioritise the identified risks in this research is felt.

Many researchers developed risk evaluation models of RE investment projects based on different methods. Ioannou et al. (2017) provided a literature review of the various methods that have been used to model risks and uncertainties in renewable energy projects. They reviewed more than 160 papers in different phases of renewable energy projects, including the planning and feasibility, construction and operation and maintenance phases. They classified the risk evaluation models into 'semi-quantitative' and 'quantitative' method groups. Table 1 summarises the previous risk evaluation models of renewable energy

Table 1. Models of Renewable Energy Projects.

Reference	Group	Methodology	Project Type
Kucukali (2011)	Semi-quantitative	Fuzzy logic	Hydropower plant
Martínez-Ceseña and Mutale (2011)	Quantitative	Real option	Renewable energy
Caralis et al. (2014)	Quantitative	Monte Carlo simulation	Renewable energy
Shafiee (2015)	Semi-quantitative	Fuzzy ANP	Wind power plant
Arnold and Yildiz (2015)	Quantitative	Monte Carlo simulation	Bio-energy plant
Kucukali (2016)	Semi-quantitative	Fuzzy AHP	Wind energy
Liu and Zeng (2017)	Semi-quantitative	System dynamic	Renewable energy
Kim et al. (2017)	Quantitative	Real option	Renewable energy
Wu et al. (2019)	Semi-quantitative	Fuzzy ANP	Solar power plant
Serrano-Gomez and Munoz-Hernandez (2019)	Combination	AHP, Monte Carlo simulation	Renewable energy

Source: The authors.

In the semi-quantitative method group, the studies use the multi-criteria decision-making (MCDM) technique to prioritise the identified risks. For example, Kucukali (2011) investigated the effect of 10 external risks, including ‘social’, ‘political’, ‘economic’ and ‘environmental’ risks, on the success of wind energy projects by using a risk scoring method (RSM). The results showed that ‘connection to the electric grid’ and ‘change in regulation and policy’ were the most important risks in wind energy projects in Turkey. Gul et al. (2020) emphasised the importance of commercial risks in RE projects in developing countries using a system dynamic model.

Moreover, Wu et al. (2019) proposed an integrated model of MCDM, the triangular fuzzy number (TFN) and analytic network process (ANP), to assess the risks in the construction of offshore photovoltaic power generation projects in China. According to their results, among ‘micro-economic’, ‘technical’, ‘environment’ and ‘management’ risks, the group of ‘management’ risks was the most essential part of these projects. They emphasised in their model that not only does the process of risk evaluation usually occur in the preliminary stage of power plant projects but also the judgement of experts relies on their previous experience and knowledge. As a result, ambiguity and uncertainty are present in the process of risk assessment. In this regard, Wu et al., like other researchers, utilised the fuzzy theory in their risk evaluation models in RE projects (Shafiee, 2015; Wu et al., 2019; Xinyao et al., 2017).

Fuzzy means blurred, frayed or fluffy. Fuzzy logic was introduced by Zadeh (1965) as a branch of modern mathematics. It is a suitable method to use in approximate reasoning that involves human thinking. Also, construction projects and linguistic variables are useful tools for solving these problems (Chan et al., 2009; Panda & Pattanaik, 2002). Carr and Tah (2001) used fuzzy logic in construction risk assessment for the first time. Since then, many researchers have applied and modified fuzzy logic in their risk evaluation models. Islam et al. (2018) proposed and validated a fuzzy group decision-making (FGDM) model for risk assessment in power plant projects. Using this model, they tried to improve the reliability of the risk assessment results by using a quantitative risk aggregation process instead of fuzzy if-then rules and considering experts' judgement ability. In a similar study, Islam et al. (2019) showed the capability of the FGDM model to use a group of experts in the process of risk assessment in complex construction projects, like power plant projects, again. However, all the studies in this group just prioritise the identified risks and cannot provide financial analysis for investors. In the investor's perspective, having detailed information about the financial analysis with respect to the risks is necessary.

In the quantitative method group, the studies model the cash flow of the RE investment projects in the entire life cycle of the project with regard to the uncertainties and risks. Different risks affecting investment cost, operation and maintenance cost and income of the projects are considered. Kim et al. (2017) applied a real option model to consider the uncertainties and volatility in RE projects. Pereira et al. (2014), and after them, in 2015, Arnold and Yildiz, presented models to evaluate risks in RE projects based on the Monte Carlo simulation (MCS) method. In fact, the profitability of the wind energy investment involved uncertainties that could be treated by using MCS (Martínez-Ceseña & Mutale, 2011). In these models, therefore, they used MCS to estimate the economic parameter of the projects, with regard to the impact of uncertainties. Although the uncertainties in the interest rate and value of energy were considered in these models, the uncertainties in other parameters of cash flow were ignored.

To fill the gap of the integrated quantitative and semi-quantitative method groups, this article proposes a combined model to evaluate the investment risks in wind energy projects. The presented model can evaluate the importance of different risks, as well as provide a financial analysis based on the uncertainties in the cash flow of the investment. The proposed model makes the following specific contributions:

- Provides a comprehensive identification of critical risk factors in wind energy projects;
- Prioritises the identified risks with a modified FGDM model to improve the fuzzy risk assessment process by using a quantitative risk aggregation process and considering the experts' ability and their expertise in wind energy projects;
- Proposes certain responses to important risks;
- Develops a financial model with respect tof different uncertainties and risks in the entire cash flow of the project by using MCS; and
- Establishes an integrated model that uses the output of the first risk analysis phase in the second phase of risk evaluation to provide detailed information to investors about the risk level of the projects, most important

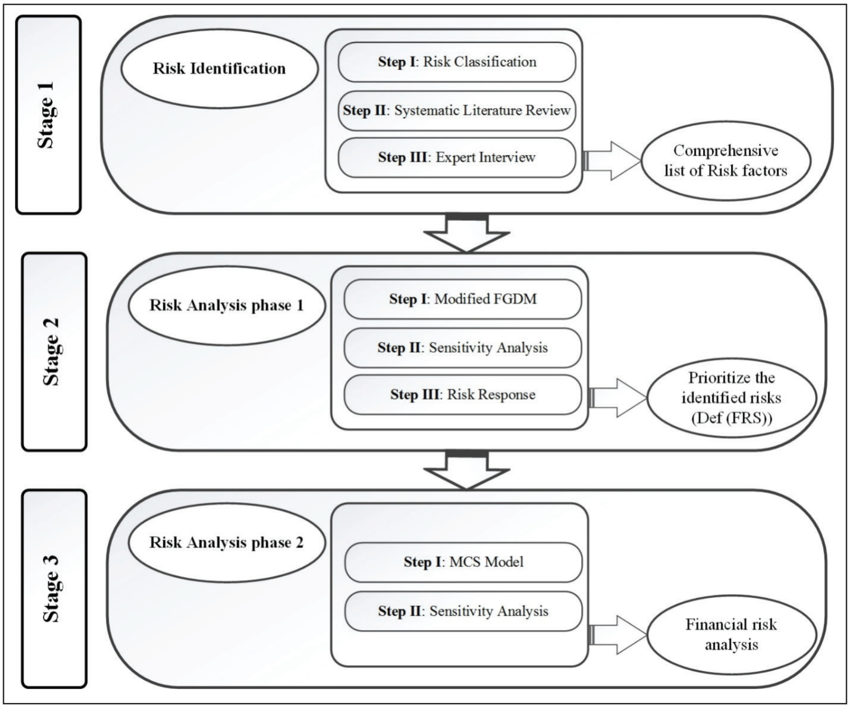


Figure 1. Structure of the Three-stage Risk Evaluation Model.

Source: The authors.

III. Methodology

The proposed risk evaluation model is carried out through three main stages: risk identification, risk analysis phase 1 and risk analysis phase 2. Each stage consists of various steps. The structure of the proposed model is shown in Figure 1. The details of the proposed model are as follows.

Stage 1: Risk identification
The purpose of the first stage is to identify the risks associated with different aspects of wind energy investment projects. This stage is completed through three steps.

Step I: Risk classification
The classification of risks forms the following review to identify risks comprehensively. As observed in the literature, there is no standardised classification of risks in wind energy projects (Gatzert & Kosub, 2016). Therefore, in this article, the classification is proposed based on the literature review of Ioannou et al. (2017). The risks are classified under four main groups: technical, economic, social and governmental and environmental.

Step II: Systematic literature review

The second step includes a literature review based on a systematic literature review (SLR) method. The SLR approach is a way to conduct research systematically and transparently and by restricting the researcher bias (Denyer & Tranfield, 2009). The papers are searched in the databases of Google Scholar and Taylor & Francis Online. To find relevant previous papers, the researched keywords are categorised into two different groups: (a) 'risk management, Project management, Risk assessment and Risk analysis' and (b) 'renewable energy, windfarm and wind power investment'. The papers are chosen based on the following criteria: (a) it implied the risk factors in wind energy projects; (b) it was published in a refereed journal; and (c) it was published in English. The initial review is supplemented with additional papers' citation check (Taroun, 2014). Finally, 25 papers are fully reviewed to identify the final list of risk factors.

Step III: Expert interview

Three semi-structured interviews with experts with a rich experience in wind energy projects are conducted in the third step. The participants include a project manager, risk manager and an avid and active researchers in RE projects. The experts use their personal experience and literature review to check and complete the list of risk factors. According to the experts' recommendation, some of the risk factors are merged or deleted because they have equal meaning and implication, or a new risk factor is added to our list. As a result, a comprehensive list of risk factors is developed at the end of the first stage.

Stage 2: Risk analysis phase 1

The objective of this stage is to prioritise the risks identified in the previous stage and then propose appropriate responses to the important risks. This stage involves three steps.

Step I: Modified FGDM

In this step, the FGDM model developed by Islam et al. (2018), with some modification, is applied to prioritise the identified risks in wind energy projects. In this model, the experts are asked to evaluate the risks based on the most common method of probability and impact (*P–I*). (Taroun, 2014) The experts are asked to evaluate the probability of the occurrence of individual risk (*P*) and the impact of the risk on the project cost (*I*). The step-by-step procedure of the model is as follows.

Linguistic variable and fuzzy triangular number (FTN) definition: Based on Table 2, the experts are asked to evaluate the *P* and *I* of each risk by choosing one of the linguistic variables: none, very low, low, medium, high, very high and extremely high. Each one equals a FTN. An FTN provides a 3-point estimate rather than a crisp value for risk level, where the FTN membership function is as shown in Equation (1) (Nieto-Morote & Ruz-vila, 2011).

Table 2. Linguistic Variables and Corresponding FTN Numbers.

Probability of the Occurrence (*P*) or Impact on Project Cost (*I*)	FTN	Description
Extremely high	(0.9, 1 ,1)	The risk will occur certainly, and extremely significant for project cost
Very high	(0.7, 0.9, 1)	Very high chance of risk event occurring, and most significant for project cost
High	(0.5, 0.7, 0.9)	High chance of risk event occurring, and significant for project cost
Medium	(0.3, 0.5, 0.7)	Likely chance of risk event occurring, and moderately significant for project cost
Low	(0.1, 0.3, 0.5)	Rare chance of the risk event occurring, and less significant for project cost
Very low	(0, 0.1, 0.3)	Very rare chance of the risk event occurring, and very less significant for project cost
None	(0, 0, 0.1)	Risk event will never occur, and not significant for project cost

Source: Islam et al. (2018).

$$\mu(l.m.u) = \begin{cases} 0 & x \le a \\ \dfrac{x-l}{m-l} & l \le x \le m \\ \dfrac{u-x}{u-m} & m \le x \le u \\ 0 & u \le x \end{cases} \tag{1}$$

Expert judgement: After receiving the experts' opinions on P and I, as shown in Table 2, a fuzzy decision matrix (FDM) is formed for each risk, as shown in Equation (2), where l, m and u = low, medium and upper values of P or I, based on Table 2, and N = number of experts that are involved in this research.

$$\left(\mathrm{FDM}^{r}_{P/I}\right) = \begin{Bmatrix} & l_1 m_1 u_1 & \\ & l_2 m_2 u_2 & \\ . & . & . \\ . & . & . \\ & l_n m_n u_n & \end{Bmatrix} \tag{2}$$

The judgement of the experts is dependent on their expertise and knowledge of wind energy projects. On the other hand, these projects are new in the Middle East, in contrast to other construction projects. Therefore, each expert can have a different opinion. To improve the result of the risk evaluation model, it is possible to consider weights for the experts' opinions based on their expertise and ability in this subject. For this purpose, Monzer et al. (2019) conducted a research to determine which criteria with what weights should be considered to improve the aggregation process in wind energy risk assessment. Based on their result, the score (S_i) and weight of the professional competence (W_i) of each expert can be calculated using Equations (3) and (4).

$$S_i = [0.26 \times \mathrm{AK}] + [0.17 \times \mathrm{EX}] + [0.22 \times \mathrm{PP}] + [0.36 \times \mathrm{RP}] \tag{3}$$

In Equation (3), AK = academic knowledge, EX = experience, PP = professional performance and RP = risk management practice. Each section has a 10-point score that is determined by the experts' responses to the questions in the questionnaire (Appendix A). Therefore, the total S_i will be scored out of 10 for each expert based on their response to the questions. Finally, W_i is computed using Equation (4):

$$W_i = \frac{S_i}{\sum_{i=1}^{n} S_i} \quad . \quad \sum_{i=1}^{n} W_i = 1 \tag{4}$$

Fuzzy calculation: After calculating the weights, the FDM is transformed into a weighted FDM (WFDM) using Equation (5):

$$\left(\mathrm{WFDM}^{r}_{P/I}\right) = \left(\mathrm{FDM}^{r}_{P/I}\right) \times W_i = \left\{\begin{matrix} & l_1 w_1 m_1 w_1 u_1 w_1 & \\ & l_2 w_2 m_2 w_2 u_2 w_2 & \\ . & . & . \\ . & . & . \\ & l_n w_n m_n w_n u_n w_n & \end{matrix}\right\} \tag{5}$$

Based on the WFDM, the fuzzy score (FS) for P and I is calculated according to all experts' opinions:

$$\left(\mathrm{FS}^{r}_{P/I}\right) = \left[\sum_{i=1}^{n} l_i w_i . \sum_{i=1}^{n} m_i w_i . \sum_{i=1}^{n} u_i w_i\right] \tag{6}$$

After calculating FS for the P and I of each risk, the fuzzy risk score (FRS) is calculated using Equation (7), considering both P and I to find important risks. Equation (7) is adapted from Xu et al. (2010):

$$(\mathrm{FRS}_r)_{l.m.u} = \left[\sqrt{(\mathrm{FS}^{r}_{\mathrm{RL}}) \times \left(\mathrm{FS}^{r}_{\mathrm{C}}\right)_P}\,\right]_{l.m.u} \tag{7}$$

Finally, defuzzification is required to define the risk level of each risk and find important risks. For this purpose, Equation (8) is adapted from Platon and Constantinesu (2014). Therefore, the identified risks are sorted according to the $f(x)$ value, finally.

$$f(x_i) = \left(\mathrm{FRS}_r\right)\mathrm{def} = \frac{\left(\mathrm{FRS}_r\right)_l + 4\left(\mathrm{FRS}_r\right)_m + \left(\mathrm{FRS}_r\right)_u}{6} \tag{8}$$

Risk score of a group (RSG) and project risk score (PRS) calculation: RSG and percentage of RSG are calculated based on the average FS of risks in each group as given by Equation (9). PRS is also calculated using the average RSG, as given by Equation (10). Therefore, PRS indicates the overall project risk and RSG illustrates the most important group of risks in these projects.

$$\mathrm{RSG}_a = \frac{1}{m}\sum\nolimits_{r=1}^{m}\left(\mathrm{FRS}_r\right)\mathrm{def}\ .\ \%\mathrm{RSG}_a = \frac{\mathrm{RSG}_a}{\sum\nolimits_{a=1}^{n}\mathrm{RSG}_a} \tag{9}$$

$$\mathrm{PRS} = \frac{\sum\nolimits_{a=1}^{n}\mathrm{RSG}_a}{n} \tag{10}$$

In Equation (9), m = number of risks in each group, and in Equation (10), n = number of group risks.

Step II: Risk response
After assessing the risks, we classified them into three groups—high risk (H), moderate risk (M) and low risk (L)—based on their FRS. High risks are the risks with FRS > 0.5 (Islam et al., 2018). These risks are the most influential risks of wind energy projects. Therefore, we try to propose appropriate responses to the top high risks. For this purpose, the responses are classified into the two groups of risk mitigation and risk transfer according to the experts' opinions, previous studies and researchers' suggestions.

Step III: Sensitivity analysis
In this step, a sensitivity analysis is performed to find the effect of considering the weight of the experts' opinion. For this purpose, the result of the FGDM model is compared in modified and unmodified conditions.

Stage 3: Risk analysis phase 2
The objective of this stage is to propose a financial analysis of the cash flow under uncertainty based on the result of the FGDM model in the first risk analysis phase. The result of this stage will provide more detailed financial information for investors with regard to the risks and uncertainties. This stage involves two steps, as follows.

Step I: MCS model
In this step, an MCS model is applied to propose a financial analysis for these projects. The model aims to consider the effect of different risks on the cash flow of the project. Also, the model shows how the capability of an appropriate risk evaluation model affects the financial parameters of the project. The step-by-step procedure of the model is as follows.
Cash flow mathematical definition: The mathematical model of the cash flow is established to obtain financial parameters of the investment. The first part of the cash flow is the total investment cost (C_T). C_T is calculated based on Equation (11) (Da Silva Pereira et al., 2014). It is assumed that C_T happened at the first point of the cash flow completely.

In Equation (11), C_T = total investment cost, C_p = primary development phase cost, C_e = equipment cost, C_t = transportation cost, C_i = installation cost, C_{in} = insurance and tariff cost, C_s = structures cost and C_g = grid connection cost.

The second part of the cash flow is the operation and maintenance cost ($C_{O\&M}$), which repeats each year during the project life cycle. $C_{O\&M}$ is calculated based on Equation (12) (Da Silva Pereira et al., 2014):

$$C_{O\&M} = C_{m\&e} + C_w + C_m \tag{12}$$

In Equation (12), $C_{O\&M}$ = operation and maintenance cost, $C_{m\&e}$ = material and equipment cost, C_w = wage cost and C_m = maintenance cost.

Finally, the last part of the cash flow is the annual income of the project. The income of the project includes a direct income from selling energy and indirect income by preventing CO_2 emissions. The annual income is calculated using Equation (13).

$$Q_T = Q_e + Q_c \tag{13}$$

In Equation (13), Q_T = total annual income, Q_e = selling energy income and Q_c = preventing-CO_2-emissions income. Also, Q_e and Q_c are calculated by Equation (14), as follows:

$$Q_e = P_e \times E_i Q_c = P_c \times E_c \tag{14}$$

In Equation (14), P_e = price of sold energy per kilowatt hour, E_i = the amount of energy produced and injected into the grid annually, P_c = the value of prevented CO_2 per ton and E_c = the amount of prevented CO_2 (around 0.65 ton/kWh).

Eventually, the financial parameters, including net present value (NPV) of the project and P (total cost of producing energy per kWh) are calculated based on C_T, $C_{O\&M}$ and Q_T in Equations (15) and (16):

$$\mathrm{NPV} = -C_T + \frac{Q_{T1} - C_{O\&M}}{(1+i)} + \frac{Q_{T2} - C_{O\&M}}{(1+i)^2} + \ldots + \frac{Q_{Tn} - C_{O\&M}}{(1+i)^n} + \mathrm{SV} \tag{15}$$

$$P = \frac{C_T + \frac{C_{O\&M}}{1+i} + \frac{C_{O\&M}}{(1+i)^2} + \ldots + \frac{C_{O\&M}}{(1+i)^n} - \mathrm{SV}}{\sum_{i=1}^{n} E_c} \tag{16}$$

where SV refers to the present salvage value.

Input variables and probability distribution function: This step is the most important part of the MCS model (Arnold & Yildiz, 2015). The purpose of this step is to provide confidence estimates about the output variables of the model, which are NPV and P. These variables are directly dependent on the behaviour of the independent variables C_T, Q_T, $C_{O\&M}$, SV, i, E_i and E_c, which have uncertainties. It is assumed that these variables are independent and have not any correlation.

For instance, increasing C_e will not affect installation cost, wage cost, etc. MCS relies on large numbers of random sampling of input variables to evaluate the output variables with respect to the risks (Platon & Constantinescu, 2014).

Koukal et al. (2017) used a triangular assumption for the probability distribution function of variables in their MCS model to propose the financial analysis of wind energy projects. They used the experts' judgement to determine the three points of triangular assumption.

In this article, an integrated model is established to determine the probability distribution of input variables. The triangular assumptions are determined based on the result of the FGDM model in the first risk analysis phase, as follows:

1. Receive the estimated amount of each parameter of cash flow (most likely value) according to project information (E).
2. Determine the risks that affect each parameter (C_p, C_e, etc.) among the identified and analysed risks in the first phase according to the three expert opinions (involved in stage 1).
3. Determine the factor (R) based on the result of the FGDM model for each parameter, as given by Equation (17), in which m is the number of risks that affect each parameter:

$$R = \frac{(\mathrm{FRS}_1)\mathrm{def} + (\mathrm{FRS}_2)\mathrm{def} + \ldots + (\mathrm{FRS}_m)\mathrm{def}}{m} \tag{17}$$

4. Calculate the probability distribution of input variables by considering the maximum of 50 per cent variation (Koukal & Piel, 2017). For instance, the triangular assumption of C_e is calculated by Equation (18):

$$f(C_e) = \left[\left(E_{C_e} - \frac{E_{C_e}}{4} \times R_{C_e}\right).\left(E_{C_e}\right).\left(E_{C_e} + \frac{E_{C_e}}{4} \times R_{C_e}\right)\right] \tag{18}$$

Finally, the MCS model runs 10,000 trials to achieve the model outputs' distribution.

Step II: Sensitivity analysis

In this step, a sensitivity analysis is completed based on the MCS model. The purpose is to find the most influential parameters in cash flow on the profitability of the project and try to pay more attention to these parameters and the risks that affect them.

IV. Application of the Proposed Methodology: A Case Study of the Middle East

To demonstrate the capability of the proposed risk evaluation model, it is applied to a wind farm in the Middle East. The basic technical characteristics of the project are summarised in Table 3, which also presents the financial information of the project.

Table 3. Basic Technical Characteristics and Financial Information ($ million) of the Case Study: Siahpoosh Wind Energy Project.

Name of the project	Siahpoosh	Location	Qazvin, Iran
Total capacity	61.2 MW	Number of turbines	18–3.4 MW
$E_{i(expected)}$	246.6 GWh	$E_{c(expected)}$	160,000 ton
Project life cycle	20 years	I	10%
C_p (primary development phase cost)	5	$C_{m\&e}$ (material and equipment cost)	0.55
C_e (equipment cost)	40	C_w (wage cost)	0.45
C_t (transportation cost)	3	C_m (maintenance cost)	1
C_i (installation cost)	1	$C_{O\&M}$ (operation and maintenance cost)	2
C_{in} (insurance and tariff cost)	11	P_{i1} (price of generated energy per kWh in the first 10 years)	0.09 US$/kWh
C_s (structures cost)	4	P_{i2} (price of generated energy per kWh in the last 10 years)	0.03 US$/kWh
C_g (grid connection cost)	6	P_c (the value of prevented CO_2)	1 US$/ton
C_T (total investment cost)	70	SV (present salvage value)	4

Source: The authors.

Notes: *E* is the estimated amounts of each part of cash flow, are presented based on the project information.
Turbines are imported from outside of Iran.
$E_{i(expected)}$: expected annual electric generation and $E_{c(expected)}$: expected annual prevented greenhouse gas emissions.

V. Results and Discussion

In this section, the results of the proposed model for our case study are presented step by step.

Stage 1: Risk identification
The risks associated with different aspects of wind energy investment projects are presented in Table 4 based on the result of the first stage. The description of each risk and its references are mentioned, additionally.

Stage 2: Risk analysis phase 1
The main purpose of this stage is to analyse the risks identified in the previous stage based on the experts' opinions. For this purpose, experts with high knowledge of and experience in different power plant projects are selected to complete the questionnaires. These heterogeneous experts would provide their opinions to assess the probability of occurrence and impact of each risk. Questionnaires were hand-delivered or mailed to 50 experts, and a total of 17 experts returned their completed questioners. Finally, based on their answers, using Equations (3) and (4) (Monzer et al., 2019), the score and weight of each expert's opinion are calculated for further assessment. The summary of the

able 4. Risks Associated with Different Aspects of Wind Energy Investment Projects.

isk Group	Risk Factors	Risk Group	Risk Factors
echnical	Variation of availability of natural resources: wind speed (T1)	Economic	Price fluctuation in the international market (EC1)
	Incompleteness of basic studies at the beginning (T2)		Dependency on the international market importing raw materials (EC2)
	Inadequate and incomplete design (T3)		Increasing rate of inflation (EC3)
	Insufficient technical background and experiences on a specific project type (T4)		Changing bank interest rate (EC4)
	Incorrect selection of equipment, materials and technology (T5)		Changing currency exchange rate (EC5)
	Unavailability of sufficient and skilled humans (T6)		Insufficient funding and financing (EC6)
	Conflict between the teams involved in the project (T7)		Changing orders and scope (contract risks) (EC7)
	Contractor, subcontractor and supplier's incapability (counterparty risk) (T8)		High payback (EC8)
	Failure of plant/equipment during the installation (T9)		Occurrence of serious problems in the essential part (EC9)
	Shortage of material and equipment (T10)		Lack of skilled persons for employment during the operational phase (EC10)
	Managerial risks (T11)		Poor finance management (EC11)
	Quality of foundation of the wind machine tower (T12)		Increase in realisation time (EC12)
	Inadequate or undulating topography (T13)		Natural disasters: flooding, bad weather, earthquake (EC13)
	Fluctuation of production rates (T14)		Lack of appropriate maintenance (EC14)
	Progressiveness of technology in future (T15)		Market changes (EC15)
	Connection to the electric grid (T16)		Market competitiveness (EC16)

(Table 4 Continued)

(Table 4 Continued)

Risk Group	Risk Factors	Risk Group	Risk Factors
	Difficult transportation of blades, towers and turbines (T17)		Change in energy price (EC17)
	Immaturity of technology and quality of products (T18)	Environmental	Insufficient environmental requirement and standards (EN1)
	Unexpected accident and injuries (T19)		Inadequate environmental impact assessment (EN2)
	Inadequate and strict safety regulations (T20)		Negative effect on environment (EN3)
Social and governmental	Social and public acceptance (SG1)		Damage of physiological and psychological health of humans and ecology (EN4)
	Political stability (SG2)		
	Change in regulation and policy (SG3)		
	High-level bureaucracy (SG4)		

Sources: Diógenes et al. (2019), Zhao et al. (2019), Islam et al. (2018), Guo et al. (2018), Liu et al. (2018), Loannou et al. (2017), Xinyao et al. (2017), Macchiaroli et al. (2017), ...lik (2017), Tavakolan and Etemadinia (2017), Angelopoulos et al. (2017), Noothout et al. (2016), Guerrero-Liquet et al. (2016), Gatzert and Kosub (2016), Li and Li (2015), Gang ...015), Jankauskas et al. (2014), Jin et al. (2014), Michelez et al. (2011) and De Jager et al. (2008).

Table 5. Calculation of Score and Weight of Experts in the Modified Model.

Expert	Score (out of 10)	Weight (out of 1)	Expert	Score (out of 10)	Weight (out of 1)
1	4.65	0.054	10	7.81	0.091
2	2.86	0.033	11	3.70	0.043
3	8.68	0.101	12	4.08	0.047
4	5.69	0.066	13	7.66	0.089
5	1.04	0.012	14	5.55	0.065
6	7.15	0.083	15	2.79	0.032
7	3.87	0.045	16	7.78	0.090
8	4.61	0.054	17	4.77	0.055
9	3.35	0.039			

Source: The authors.

Finally, FGDM calculation is performed, and the results are provided in Table 6. Because of space limitations, only the top 30 risks with their defuzzified scores are provided. The result shows that the most important risks are 'change in regulation and policy', 'dependency on the international market for importing raw material', 'market competitiveness', 'changing currency exchange rate' and 'difficult transportation of blades, towers and turbines'.

Table 6. FGDM Risk Analysis Results.

		P		*I*		FRS	
Rank	Risk Code	Score	Level	Score	Level	Score	Level
1	SG3	0.703	H	0.815	H	0.757	H
2	EC2	0.752	H	0.742	H	0.748	H
3	EC16	0.645	H	0.852	H	0.741	H
4	EC5	0.592	H	0.849	H	0.708	H
5	T17	0.706	H	0.667	H	0.686	H
6	T4	0.592	H	0.780	H	0.679	H
7	T19	0.579	H	0.726	H	0.648	H
8	T13	0.599	H	0.656	H	0.627	H
9	EC15	0.503	H	0.718	H	0.600	H
10	T16	0.466	M	0.679	H	0.561	H
11	EC3	0.389	M	0.637	H	0.497	M
12	T1	0.392	M	0.584	H	0.478	M
13	EC7	0.366	M	0.597	H	0.467	M
14	EC17	0.342	M	0.631	H	0.463	M
15	T15	0.518	H	0.358	M	0.430	M

(Table 6 Continued)

		P		*I*		FRS	
Rank	Risk Code	Score	Level	Score	Level	Score	Level
16	EC11	0.294	L	0.631	H	0.429	M
17	EC8	0.332	M	0.556	H	0.429	M
18	T10	0.335	M	0.547	H	0.428	M
19	SG2	0.264	L	0.673	H	0.419	M
20	EC9	0.301	M	0.552	H	0.406	M
21	SG4	0.299	L	0.534	H	0.399	M
22	T9	0.283	L	0.553	H	0.394	M
23	T14	0.282	L	0.547	H	0.391	M
24	EC13	0.195	L	0.797	H	0.388	M
25	EC12	0.299	L	0.488	M	0.381	M
26	T7	0.301	M	0.470	M	0.376	M
27	EN4	0.273	L	0.513	H	0.373	M
28	T18	0.268	L	0.515	H	0.369	M
29	T2	0.254	L	0.532	H	0.366	M
30	SG1	0.237	L	0.561	H	0.362	M

Source: The authors.

Note: Score ≥ 0.5 = high (H); 0.3 < score < 0.5 = medium (M); and score ≤ 0.3 = low (L).

After identifying the important risks in Table 6, the percentages of RSG and PRS are calculated. The result shows that the most important risk groups in these projects are 'economic' and 'technical' risks. Also, the risk contribution by different risk groups is shown in Figure 2. On the other hand, the result shows PRS = 0.424. It means that the overall level of risk is medium; therefore, an appropriate risk management process can guarantee the profitability of investment in these projects.

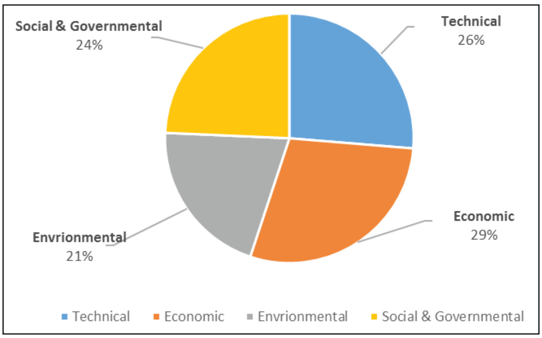


Figure 2. Risk Contribution by Different Groups.

Discussion of Important Risks

Based on the model results, the most important risk in these projects is 'change in regulation and policy'. This risk has resulted from changes in supportive government policy. In developing countries, the government has a crucial role in supporting RE projects. Government monetary policies have a great contribution in shaping economic factors in the country (Hossain & Maitra, 2020). Therefore, finding an appropriate risk response is necessary. The risk transfer responses include using different political risk insurances like those of the MIGA (Multilateral Investment Guarantee Agency) or the World Bank. Also, the impact of the risk can be mitigated through using social activities and attracting the local communities support.

The second important risk is 'dependency on the international market for importing raw material'. In order to mitigate the impact of this risk, it is possible to have more investment in domestic companies first. It will help develop the knowledge of RE technology in the country. On the other hand, the government can help develop national companies by offering a higher guaranteed price for those projects that use domestic technologies. The other important risk is 'market competitiveness'. The low price of fossil fuels in countries is a major obstacle to developing RE projects (Aslani et al., 2012; Zarnegar, 2018). Provision of long, guaranteed contracts by the government is a suitable way to mitigate the impact of this risk.

Another significant risk is 'changing currency exchange rate'. Currency exchange becomes an influential parameter in the profitability of these investments. The government, by providing the possibility of exporting energy from these projects to neighbourhood countries, can help mitigate the impact of this risk, because the impact of changes in the currency exchange rate will reduce if the income and outcome of the investment are the same currency. Finally, the 'difficult transportation of blades, towers and turbines' is another serious risk in this project. Choosing an appropriate location and site can help mitigate this risk. Besides using the available insurances for transportation and installation of towers, investing in turbines and other components is a way to transfer this risk (Gatzert & Kosub, 2016).

Sensitivity Analysis I

We proposed a modified model to consider the competencies of the experts in risk assessment. Comparing the results of the modified model with those of the unmodified model shows the increasing concern about these projects caused by increasing the level of expertise in RE projects. The most important risk in the modified model is 'change in regulation and policy', and that in the unmodified model is 'market competitiveness'. Figure 3 provides a summary of the sensitivity analysis results. It shows that experts with more experience in this filed have more concerns about these projects, with more emphasis on the technical aspect.

Top Risks in Modified Model	FRS	Top Risks in Unmodified Model	FRS	**Percntage of changes** (Modifed model compare to Unmodified)	
SG3	0.757	EC16	0.749	EC14	9.77
EC2	0.748	SG3	0.749	T2	9.23
EC16	0.741	EC2	0.747	T1	8.65
EC5	0.708	T17	0.687	T8	6.53
T17	0.686	EC5	0.685	T9	6.32
T4	0.679	T4	0.663	T20	5.46
T19	0.648	T9	0.626	EC14	5.29
T13	0.627	T13	0.608	T7	4.95
EC15	0.6	EC15	0.593	T10	-4.92
T16	0.561	T16	0.557	EC12	4.75

Figure 3. Summary of Sensitivity Analysis in Stage 2.

Source: The authors.

Stage 3: Risk analysis phase 2

The main advantage of the proposed model is a combination of semi-quantitative and quantitative methods. In order to integrate the risk analysis results in phase 1 and the MSC model, it is needed to determine different risks that have an impact on each cash flow parameter. For this purpose, we had a meeting between three experts with high experience in wind energy projects. The participants included a project manager, a risk manager and an avid and active researcher in RE projects. They were asked to classify the risks that have an impact on each parameter. Risks affecting the cash flow of the investment can be categorised into three groups: pre-project, post-project or both. For example, pre-completion phase risks include technical and operational risks, and post-project risks include market and maintenance risks. Legal, economic risks also generally have an impact on both (Arnold & Yildiz, 2015). Finally, based on the classification of the risks, calculation of the parameter *R* in our model is performed using Equation (17). The last step before running the MCS model is determining the probability distribution of input variables. To do so, the triangular assumptions of each cash flow parameter are determined using Equation (18) and the provided information in Table 3 and the calculated *R* parameter. The summary of the R calculation and probability distribution of input variables are shown in Table 7.

Table 7. Calculation of *R* and Probability Distribution of Input Variables of the MCS model.

Cash Flow Parameter	Affecting Risks	*R*
C_e	EC1, EC2, EC4, EC5, EC6, EC11, SG3, T10	0.517
C_i	EC5, EC6, EC11, T3, T6, T8, T9, T19, T20	0.383
C_t	EC6, EC11, T8, T17, T18	0.476
C_s	EC6, EC11, T2, T3, T8, T18	0.379
C_p	EC4, EC6, EC7, EC11, SG3, SG4	0.461
C_{in}	EC11, T20, SG3	0.477
C_g	T2, T3, T15, T16	0.427

(Table 7 Continued)

(Table 7 Continued)

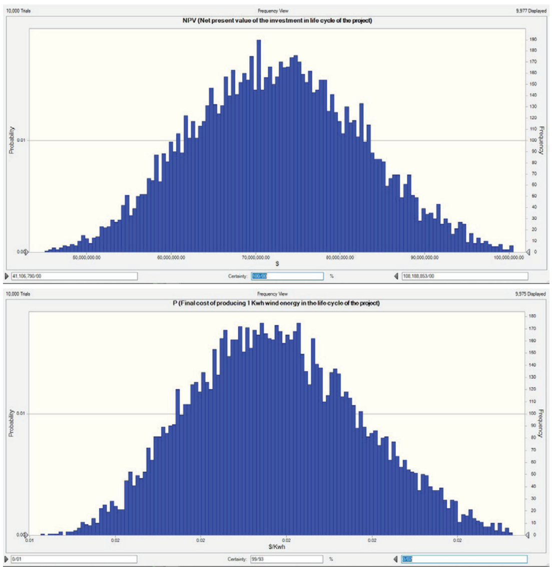
Cash Flow Parameter	Affecting Risks	*R*
$C_{m\&e}$	T2, T5, T9, EC1, EC3, EC5, EC6, EC9	0.438
C_w	EC3, EC6, EC10	0.396
C_m	EC6, EC9, EC11, EC13, EC14, T2, T5, T19, T20	0.393
E_i	EC11, EC15, EC17, T1, T2, T3, T4, T14, T18, SG3	0.491
E_c	EC11, T1, T2, T4, T14, T18, EN1, EN2	0.414
SV	EC3, T5, T15	0.427
I	EC3, EC4, EC5, EC17, SG2	0.490

Cash Flow Parameter	Min.	Most Likely	Max.
C_e ($)	34,830,000	40,000,000	45,170,000
C_i ($)	904,250	1,000,000	1,095,750
C_t ($)	2,643,000	3,000,000	3,357,000
C_s ($)	3,621,000	4,000,000	4,379,000
C_p ($)	4,423,750	5,000,000	5,576,250
C_{in} ($)	9,688,250	11,000,000	12,311,750
C_g ($)	5,395,500	6,000,000	6,640,500
$C_{m\&e}$ ($)	489,775	550,000	610,225
C_w ($)	405,450	450,000	494,550
C_m ($)	901,750	1,000,000	1,098,250
E_i (kWh)	216,339,956	246,611,520	276,883,084
E_c (ton)	143,440	160,000	176,560
SV ($)	3,573,000	4,000,000	4,427,000
I (%)	0.08	0.10	0.12

Source: The authors.

Finally, the MCS model is run for 10,000 iterations using the Crystal Ball software. Crystal Ball is considered one of the best tools for risk analysis, simulation and forecasting (Mathkour et al., 2008). The probability distribution of the two important performance measures of investment (NPV and *P*) is achieved. The result can help investors make decisions about this project based on NPV and *P*, which are calculated considering uncertainty in cash flows. The summary of the results is presented in Figure 4.

Based on the result, first, the positive mean ($ USD (United States Dollar) 72,418,713) for NPV shows that this project is profitable. The big difference between the maximum and minimum amounts of NPV emphasise the importance of an appropriate risk management process in renewable energy investment projects. Therefore, a comprehensive model that can identify the important risks, as well as providing financial analysis, is a helpful tool to help investors make their decisions. On the other hand, the result of *P* ($/kWh) shows that by increasing



	NPV ($)	P ($)
Min	41,106,790	0.01
Mean	72,418,713	0.02
Max	108,188,853	0.02
Standard deviations	9,990,747	0

Figure 4. MCS Simulation Results (NPV and P).

Source: The authors.

Sensitivity Analysis II

The result of the sensitivity analysis of NPV in the MCS model shows that the 'E_i' amount of energy produced and injected into the system has the most effect on the profitability of the projects among the cash flow parameters. Therefore, managing the risks 'variation of availability of natural resources: wind speed', 'insufficient technical background and experiences on a specific project type', 'market condition' and 'market competitiveness' is very important. The second important parameter is 'I'. The behaviour of this parameter is dependent on the economic environment. Therefore, political stability, inflation rate and the currency exchange rate will be important aspects of these investments.

Conclusion

In this article, an integrated risk evaluation model for wind energy investment projects is established. The model not only prioritises the important risks but also evaluates the effects of these risks on the cash flow of a project. It consists of three main stages. The first stage is risk identification based on an SLR. Forty-five risks distributed to the four main groups are identified in wind energy projects. The second stage includes a fuzzy risk assessment to find the important risks based on the probability of occurrence and impact of risk on project cost. Seventeen experts evaluate the identified risks by using linguistic variables. In order to improve the fuzzy risk assessment, we used a modified model based on the competency of an expert in wind energy projects. The model not only evaluates individual risks but also provides group risk analysis. The result for a case study shows that the most important risks are ‘change in regulation and policy’, ‘dependency on the international market for importing raw materials’ and ‘market competitiveness’. The group risk analysis shows that the most important group risks are ‘economic’ and ‘technical’ risks. The result emphasises the crucial role of the government in supporting wind energy investment projects.

The third stage provides a financial analysis of the project to support the process of decision-making in wind energy projects based on a Monte Carlo simulation analysis. The result of the risk analysis in the first phase is applied as the input of the risk analysis in phase 2. The NPV and *P* (cost per kWh) are calculated as the main performance measures of the project under uncertainty. The result of the case study shows that an appropriate risk management process can make a big difference in the profitability of the investment. One of the main limitations of this research is that all cash flow parameters are modelled through using triangular assumptions. Also, the risks of interaction and correlation between cash flow parameters are not investigated in this research. The purpose is to provide a simple integrated evaluation model of cash flow under uncertainty. It is recommended to consider correlation and other probability functions in future studies.

Acknowledgement

The authors acknowledge Dr Sarbajit Chaudhuri, the editor of *Arthaniti* journal, and the anonymous reviewers for their evaluation and suggestions. The opinions expressed in this article are those of the authors alone, and any errors remain the fault of the authors.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding

The authors received no financial support for the research, authorship and/or publication of this article.

Appendix A

Questionnaire to evaluate the experts’ competency:

Academic knowledge (AK):

- **Last educational level**: **Bachelor’s**□ (1 point) **Master’s**□ (3 points) **PhD**□ (5 points)
- **Do you have a research background in renewable energy?**
  - o **Yes**□ (5 points) **No**□ (0 points)

Experience (EX):

- **Work experience**:
  - o **Less than 5 years** (1 point) **5–10 years** (2 points) **10–15 years** (3 points) **More than 15 years** (5 points)
- **Do you have work experience in renewable energy? Yes** (5 points) **No** (0 points)

Professional performance (PP):

- **Career positions that you have held**: (Possible to choose several options, each having 1 point)
  - o **Project manager Executive engineer Site manager Consultor engineer**
  - o **Client team**
- **How many years have you been working in your last job?**
  - o **Less than 5 years** (1 point) **5–10 years** (2 points) **10–15 years** (3 points) **More than 15 years** (5 points)

Risk management practice (RP):

- **Do you have work experience in risk management processes?**
  - o **Yes** (5 points) **No** (0 points)
- **Do you have a research background in risk management processes?**
  - o **Yes** (5 points) **No** (0 points)

References

Abdelgawad, M., & Fayek, A. R. (2010). Risk management in the construction industry using combined fuzzy FMEA and fuzzy AHP. *Journal of Construction Engineering and Management, 136*(9), 1028–1036.

Afsharzade, N., Papzan, A., Ashjaee, M., Delangizan, S., Van Passel, S., & Azadi, H. (2016). Renewable energy development in rural areas of Iran. *Renewable and Sustainable Energy Reviews, 65*, 743–755.

Angelopoulos, D., Doukas, H., Psarras, J., & Stamtsis, G. (2017). Risk-based analysis and policy implications for renewable energy investments in Greece. *Energy Policy, 105*, 512–523.

Arnold, U., & Yildiz, Ö. (2015). Economic risk analysis of decentralized renewable energy infrastructures—A Monte Carlo Simulation approach. *Renewable Energy*, *77*, 227–239.

Aslani, A., Naaranoja, M., & Zakeri, B. (2012). The prime criteria for private sector participation in renewable energy investment in the Middle East (case study: Iran). *Renewable and Sustainable Energy Reviews, 16*(4), 1977–1987.

Balatbat, M. C., Findlay, E., & Carmichael, D. G. (2012). Performance risk associated with renewable energy CDM projects. *Journal of Management in Engineering*, *28*(1), 51–58.

Bennett, J., Baker, A., Johncox, E., & Nateghi, R. (2020). Characterizing the key predictors of renewable energy penetration for sustainable and resilient communities. *Journal of Management in Engineering*, *36*(4), 04020016.

Caralis, G., Diakoulaki, D., Yang, P., Gao, Z., Zervos, A., & Rados, K. (2014). Profitability of wind energy investments in China using a Monte Carlo approach for the treatment of uncertainties. *Renewable and Sustainable Energy Reviews, 40*, 224–236.

Carr, V., & Tah, J. H. M. (2001). A fuzzy approach to construction project risk assessment and analysis: Construction project risk management system. *Advances in Engineering Software, 32*(10–11), 847–857.

Chan, A. P., Chan, D. W., & Yeung, J. F. (2009). Overview of the application of 'fuzzy techniques' in construction management research. *Journal of Construction Engineering and Management, 135*(11), 1241–1252.

Da Silva Pereira, E. J., Pinho, J. T., Galhardo, M. A. B., & Macedo, W. N. (2014). Methodology of risk analysis by Monte Carlo Method applied to power generation with renewable energy. *Renewable Energy, 69*, 347–355.

De Jager, D., Rathmann, M., Klessmann, C., Coenraads, R., Colamonico, C., & Buttazzoni, M. (2008). *Policy instrument design to reduce financing costs in renewable energy technology projects* (PECSNL062979). International Energy Agency Implementing Agreement on Renewable Energy Technology Deployment.

Denyer, D., & Tranfield, D. (2009). Producing a systematic review. In D. A. Buchanan & A. Bryman (Eds.), *The SAGE Handbook of Organizational Research Methods* (pp. 671–689). SAGE Publications.

Diógenes, J. R. F., Claro, J., & Rodrigues, J. C. (2019). Barriers to onshore wind farm implementation in Brazil. *Energy Policy, 128*, 253–266.

El-Sayegh, S. M., & Mansour, M. H. (2015). Risk assessment and allocation in highway construction projects in the UAE. *Journal of Management in Engineering, 31*(6), 04015004.

Fera, M., Macchiaroli, R., Fruggiero, F., & Lambiase, A. (2017). Risks prioritization in decision making for wind energy investments using analytic network process (ANP). *International Journal of Applied Engineering Research, 12*, 2567–2574.

Gang, C. (2015, September). Risk analysis and evaluation of wind electric farm construction. *Proceedings of the AASRI International Conference on Industrial Electronics and Applications (IEA 2015).* Atlantis Press. https://www.atlantis-press.com/proceedings/iea-15/20570

Gass, V., Strauss, F., Schmidt, J., & Schmid, E. (2011). Assessing the effect of wind power uncertainty on profitability. *Renewable and Sustainable Energy Reviews, 15*(6), 2677–2683.

Gatzert, N., & Kosub, T. (2016). Risks and risk management of renewable energy projects: The case of onshore and offshore wind parks. *Renewable and Sustainable Energy Reviews, 60*, 982–998.

Ghosh, S. (2018). Carbon dioxide emissions, energy consumption in agriculture: A causality analysis for India. *Arthaniti: Journal of Economic Theory and Practice*, *17*(2), 183–207.

Ghoshal, T., & Bhattacharyya, R. (2008). State level carbon dioxide emissions of India: 1980–2000. *Arthaniti-Journal of Economic Theory and Practice,* 7(1–2), 41–73.

Gorjian, S., Zadeh, B. N., Eltrop, L., Shamshiri, R. R., & Amanlou, Y. (2019). Solar photovoltaic power generation in Iran: Development, policies, and barriers. *Renewable and Sustainable Energy Reviews, 106*, 110–123.

Guerrero-Liquet, G., Sánchez-Lozano, J., García-Cascales, M., Lamata, M., & Verdegay, J. (2016). Decision-making for risk management in sustainable renewable energy facilities: A case study in the Dominican Republic. *Sustainability, 8*(5), 455.

Gul, I. A., Kayakutlu, G., & Kayalica, M. Ö. (2020). Risk analysis in renewable energy system (RES) investment for a developing country: A case study in Pakistan. *Arthaniti: Journal of Economic Theory and Practice.* https://doi.org/10.1177/0976747920910824

Guo, Q., Wang, X. J., & Liang, X. D. (2018). Risk evaluation model of the whole life cycle of wind power project in China: Based on fuzzy theory. *Journal of Interdisciplinary Mathematics, 21*(5), 1061–1066.

Hossain, T., & Maitra, B. (2020). Monetary policy, trade openness and economic growth in India under monetary-targeting and multiple-indicator approach regimes. *Arthaniti: Journal of Economic Theory and Practice, 19*(1), 108–124.

Hosseini, S. E., Andwari, A. M., Wahid, M. A., & Bagheri, G. (2013). A review on green energy potentials in Iran. *Renewable and Sustainable Energy Reviews, 27*, 533–545.

Ioannou, A., Angus, A., & Brennan, F. (2017). Risk-based methods for sustainable energy system planning: A review. *Renewable and Sustainable Energy Reviews, 74*, 602–615.

Islam, M. S., Nepal, M. P., & Skitmore, M. (2018). Modified Fuzzy group decision-making approach to cost overrun risk assessment of power plant projects. *Journal of Construction Engineering and Management, 145*(2), 04018126.

Islam, M. S., Nepal, M. P., Skitmore, M., & Kabir, G. (2019). A knowledge-based expert system to assess power plant project cost overrun risks. *Expert Systems with Applications, 136*, 12–32.

Jankauskas, V., Rudzkis, P., & Kanopka, A. (2014). Risk factors for stakeholders in renewable energy investments. *Energetika, 60*(2), 113–124.

Jin, X., Zhang, Z., Shi, X., & Ju, W. (2014). A review on wind power industry and corresponding insurance market in China: Current status and challenges. *Renewable and Sustainable Energy Reviews, 38*, 1069–1082.

Kachoee, M. S., Salimi, M., & Amidpour, M. (2018). The long-term scenario and greenhouse gas effects cost-benefit analysis of Iran's electricity sector. *Energy, 143*, 585–596.

Kim, K., Park, H., & Kim, H. (2017). Real options analysis for renewable energy investment decisions in developing countries. *Renewable and Sustainable Energy Reviews, 75*, 918–926.

Koukal, A., & Piel, J. H. (2017). HICSS-Financial decision support system for wind energy—Analysis of Mexican projects and a support scheme concept. *Proceedings of the 50th Hawaii International Conference on System Sciences* 2017 (pp. 972–981). Honolulu: Hawaii International Conference on System Sciences.

Kucukali, S. (2011). Risk assessment of river-type hydropower plants using fuzzy logic approach. *Energy Policy, 39*(10), 6683–6688.

Kucukali, S. (2016). Risk scorecard concept in wind energy projects: An integrated approach. *Renewable and Sustainable Energy Reviews, 56*, 975–987.

Li, J., & Li, P. (2015). Risk assessment of wind power investment project based on matter-element extension model. *The Open Fuels & Energy Science Journal, 8*(1), 52–57.

Liu, B., Hu, Y., Wang, A., Yu, Z., Yu, J., & Wu, X. (2018). Critical factors of effective public participation in sustainable energy projects. *Journal of Management in Engineering*, *34*(5), 04018029.

Liu, X., & Zeng, M. (2017). Renewable energy investment risk evaluation model based on system dynamics. *Renewable and Sustainable Energy Reviews*, *73*, 782–788.

Martínez-Ceseña, E. A., & Mutale, J. (2011). Application of an advanced real options approach for renewable energy generation projects planning. *Renewable and Sustainable Energy Reviews, 15*(4), 2087–2094.

Mathkour, H., Assassa, G., & Baihan, A. (2008). A risk management tool for extreme programming. *International Journal of Computer Science and Network Security, 8*(8), 326–333.

Michelez, J., Rossi, N., Blazquez, R., Martin, J. M., Mera, E., Christensen, D., & Stevens, G. (2011). *Risk quantification and risk management in renewable energy projects*. Report commissioned by the IEA-Renewable Energy Technology Deployment. Altran, Arthur D Little.

Mollahosseini, A., Hosseini, S. A., Jabbari, M., Figoli, A., & Rahimpour, A. (2017). Renewable energy management and market in Iran: A holistic review on current state and future demands. *Renewable and Sustainable Energy Reviews, 80*, 774–788.

Monzer, N., Fayek, A. R., Lourenzutti, R., & Siraj, N. B. (2019). Aggregation-based framework for construction risk assessment with heterogeneous groups of experts. *Journal of Construction Engineering and Management*, *145*(3), 04019003.

Nematollahi, O., Hoghooghi, H., Rasti, M., & Sedaghat, A. (2016). Energy demands and renewable energy resources in the Middle East. *Renewable and Sustainable Energy Reviews, 54*, 1172–1181.

Nieto-Morote, A., & Ruz-Vila, F. (2011). A fuzzy approach to construction project risk assessment. *International Journal of Project Management, 29*(2), 220–231.

Noothout, P., de Jager, D., Tesnière, L., van Rooijen, S., Karypidis, N., Brückmann, R., Jirouš, F., Breitschopf, B., Angelopoulos, D., Doukas, H., Konstantinavičiūtė, I., Resch, G. (2016). *The impact of risks in renewable energy investments and the role of smart policies*. Final Report. DiaCore.

OPEC. (2018). *Share of world crude oil reserves*. https://www.opec.org/opec_web/en/data_graphs/330.htm

Panda, S. C., & Pattanaik, P. K. (2002). On optimality and competitive equilibria in the presence of fuzzy preferences. *Arthaniti: Journal of Economic Theory and Practice, 1*(1–2), 22–31.

Platon, V., & Constantinescu, A. (2014). Monte Carlo Method in risk analysis for investment projects. *Procedia Economics and Finance, 15*, 393–400.

Razmjoo, A. A., & Davarpanah, A. (2019). The role of renewable energy to achieve energy sustainability in Iran. An economic and technical analysis of the hybrid power system. *Technology and Economics of Smart Grids and Sustainable Energy, 4*(1), 7.

REN21. (2019). *Renewables 2019. Global status report*. https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf

Rolik, Y. (2017). Risk management in implementing wind energy project. *Procedia Engineering, 178*, 278–288.

Sa'eed, Z. M. (2015). Oil wealth and economic performance: The case of the non-traded sectors in Nigeria. *Arthaniti-Journal of Economic Theory and Practice*, *14*(1–2), 33–69.

Serrano-Gomez, L., & Munoz-Hernandez, J. I. (2019). Monte Carlo approach to fuzzy AHP risk analysis in renewable energy construction projects. *PloS One, 14*(6), e0215943.

Shafiee, M. (2015). A fuzzy analytic network process model to mitigate the risks associated with offshore wind farms. *Expert Systems with Applications*, *42*(4), 2143–2152.

Shahsavari, A., & Akbari, M. (2018). Potential of solar energy in developing countries for reducing energy-related emissions. *Renewable and Sustainable Energy Reviews, 90*, 275–291.

Taroun, A. (2014). Towards a better modelling and assessment of construction risk: Insights from a literature review. *International Journal of Project Management, 32*(1), 101–115.

Tavakolan, M., & Etemadinia, H. (2017). Fuzzy weighted interpretive structural modeling: Improved method for identification of risk interactions in construction projects. *Journal of Construction Engineering and Management, 143*(11), 04017084.

Tavana, A., Javid, A. E., Houshfar, E., Andwari, A. M., Ashjaee, M., Shoaee, S., & Marashi, F. (2019). Toward renewable and sustainable energies perspective in Iran. *Renewable Energy, 139,* 1194–1216.

Turner, G., Roots, S., Wiltshire, M., Trueb, J., Brown, S., Benz, G., & Hegelbach, M. (2013). Profiling the risks in solar and wind: A case for new risk management approaches in the renewable energy sector. *Swiss Reinsurance, Zurich*. https://about.bnef.com/blog/profiling-the-risks-in-solar-and-wind/

Wu, Y., Li, L., Song, Z., & Lin, X. (2019). Risk assessment on offshore photovoltaic power generation projects in China based on a fuzzy analysis framework. *Journal of Cleaner Production, 215*, 46–62.

Xinyao, J., Yongjun, H., & Fuchao, L. (2017). Research on the evaluation of wind power projects of investment risk. *Procedia Computer Science, 111*, 388–398.

Xu, Y., Yeung, J. F., Chan, A. P., Chan, D. W., Wang, S. Q., & Ke, Y. (2010). Developing a risk assessment model for PPP projects in China—A fuzzy synthetic evaluation approach. *Automation in Construction, 19*(7), 929–943.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control, 8*(3), 338–353.

Zarnegar, M. (2018). Renewable energy utilization in Iran. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 40*(7), 765–771.

Zhao, Z. Y., Chen, Y. L., & Li, H. (2019). What affects the development of renewable energy power generation projects in China: ISM analysis. *Renewable Energy, 131*, 506–517.