Modified Fuzzy Group Decision-Making Approach to Cost Overrun Risk Assessment of Power Plant Projects

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Abstract: Cost overrun risk assessment in the preliminary stages of a power plant project is laden with subjectivity, uncertainty, imprecision, and the vagueness of expert judgment. Current fuzzy approaches to risk assessment in such projects specifically require improvements in the reliability and aggregation process of experts' judgments as well as the incorporation of project phase–based risk assessment to comprehend the sources of the risks and their corresponding effects on cost overruns. In response, this study proposes a modified fuzzy group decision-making approach (FGDMA) and assesses cost overrun risks considering different project phases [(1) design and procurement, and (2) construction and commissioning] of the power plant projects of varying types, sizes/capacities, and contracts. The proposed methodology is applied to 10 different project scenarios to better understand the context of project risks and their profile and identify the critical cost overrun risks involved. This study will aid the comprehensive assessment of risks and increase the accuracy of project budgeting and contingency allocation decisions. **DOI: 10.1061/(ASCE)CO.1943-7862.0001593.**

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Introduction

Power plant projects worldwide are generally complex ventures with multifarious mechanical, electrical, and civil engineering works, undertaken within a highly interrelated technical, environmental, and sociopolitical environment (Hadikusumo and Tobgay 2015). As a result, cost overruns in power plant projects are a frequently recurring problem generally. Numerous risks from different phases of power plant projects, such as (1) project inception and design, (2) procurement, (3) construction and commissioning, and (4) operation and maintenance stages, contribute to cost overrun. Previous studies have contributed a great deal to identifying and assessing potential project risks, but have paid relatively less attention to evaluate cost overrun risks by considering different phases of power plant projects following a work breakdown structure (WBS) (Xia et al. 2017). Recent risk assessment studies have focused on a variety of power plant projects, such as nuclear, hydro, and wind projects (Hadikusumo and Tobgay 2015; Kucukali 2016; Yoo et al. 2017). However, the cost overrun risks of thermal (i.e., oil, natural gas, and coal) power plant projects, which are still considered a major source of energy supply in the world (Schiffer 2016; Singer and Peterson 2017), have not been thoroughly assessed. Rebeiz (2012), for example, investigated the critical risks of thermal power plants, but with a sole concentration of finding risks in public–private partnership (PPP) type projects.

Risk identification and assessments in the preliminary stages of power plant projects is further challenging due to lack of complete and accurate risk information available to the project team (Kucukali 2016). Expert judgment–based risk assessment, despite being invariably subjective and uncertain, is still a preferred approach (Eybpoosh et al. 2011). Although fuzzy logic can handle the subjectivity and uncertainty of expert judgments, it suffers from a lack of appropriate linguistic expressions for risk evaluation and suitable aggregation rules for risk ranking (Novak 2012) and reliability analysis (Borgonovo 2006). Furthermore, the incorporation of such critical parameters as project phases, project characteristics, and experience level of the risk evaluation experts can significantly improve the risk assessment process (Taroun 2014). Thus, there is a need to improve the fuzzy logic–based risk assessment method for power plant projects by modifying its algorithm and by adding other parameters to the assessment process.

In response, therefore, this paper proposes a modified fuzzy group decision-making approach (FGDMA) for the risk assessment of power plant projects and assesses the cost overrun risks considering different project phases and varying characteristics of thermal power plant projects. The paper makes the following specific contributions:

- It conducts a project phase-based risk assessment and presents a comparative risk scenario analysis involving different project characteristics, i.e., project type (based on fuel sources), varying project size (as the function of production capacity), and contract systems, to provide an in-depth understanding of the nature and complexity of the prevalent cost overrun risks.
- It identifies the critical risks and their possible cost impacts on power plant projects in general, and more specifically to different types of thermal power plant projects. The outcomes of this research could facilitate realistic budgeting and risk response planning and decisions at the early stages of power plant project development.
- It improves the reliability of the fuzzy logic–based risk assessment method by incorporating the experts' judgment abilities,

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data consistency analysis, and a quantitative risk aggregation process for risk ranking.

The remainder of this paper is organized as follows. First, an overview of the literature on risk assessment studies, potential risks of power plant projects, and fuzzy risk assessment methods is presented. Second, the research methodology is discussed, with a particular focus on fuzzy group decision making, application of expert judgment, and consistency analysis for risk assessment. The results of the analysis are discussed next, followed by the sensitivity analysis. Finally, concluding remarks and recommendations for future research and to professionals are presented.

Research Background

Risk Assessment Studies of Power Plant Projects

Table 1 summarizes previous studies on the risk assessment of power plant projects. It indicates that these studies have mostly focused on risk assessment in general and particularly with the nuclear power plant, hydropower, and wind power projects. They have paid less attention to the cost overrun risk assessment of thermal power plant projects. Thermal power plants—specifically oil, natural gas, and coal-based plants—have been recognized as the major source of energy worldwide (Schiffer 2016), and the demand for such projects will continue to increase for the next 25 years to ensure a sustainable energy supply (Singer and Peterson 2017). However, such projects have alarmingly huge cost overruns (Sovacool et al. 2014), and therefore a comprehensive understanding of the construction risks involved is crucially important in effectively controlling their budgets. The characteristics (i.e., technical, economic, stakeholder, policy, spatial, and environmental) of these plants are considerably different in many cases from those of nuclear, hydro, and wind power plants (Gilbert et al. 2017; Sovacool et al. 2014). Their likelihood and consequence of cost overruns also significantly differ by project type, size, and contracting system (Sovacool et al. 2014). Therefore, existing studies on nuclear, hydropower, and wind power project risks do not reflect the real risk scenarios and exposure of thermal power plant projects.

Potential Risks of Power Plant Projects

Power plant projects invariably encounter many risks and often fail to deliver within their estimated cost, and many studies have been conducted to assess these risks (Table 1). Among others, Xia et al. (2017) studied the lifecycle cost overrun risks involved in hydropower plant and other infrastructure projects, where the causal relationships between the risks motivated them to use a modified Bayesian network method. In their study, government corruption, bureaucracy, tight schedules, lack of adequate competition at the tender stage, government interference, and defective design were found to be the most significant risks for project cost overrun. Liu et al. (2017) investigated the most significant potential risks in the design phase of design-build power plant and other infrastructure projects, finding that design risks have a critical impact on project performance. By analyzing the risks using a structural equation model (SEM) and considering the direct relationship between the risks and project performance, Liu et al. (2017) also found that an incompetent design team, information inaccuracy, and delays to be the most influential risks affecting project performance in terms of time, cost, quality, and safety.

Li and Wang (2016) also evaluated the cost overrun risks of (PPP) power plant projects in China. Focusing on such country-specific risks as sociopolitical, economic, and legal issues and applying fuzzy analytical hierarchy process (AHP) for project risk analysis, they found financial feasibility, financing of the environmental risks, government stability, and improper risk allocation among the project parties to be the most significant cost overrun risks. Kucukali (2016) also investigated the external risks—sociopolitical, environmental, and economic—causing loss of revenue. Using a risk scorecard method (RSM) to identify the significant cost overrun risks involved, they identified that changes in laws and regulations, environmental issues, local community, grid connection, and land use and permits had a significant impact on wind energy projects. Similarly, Yoo et al. (2017) proposed a risk breakdown structure (RBS) for nuclear power plant projects, calculating total risk score (TRS) by integrating TRS with activity costs to evaluate the cost impacts of identified risks in corresponding project phases.

Hadikusumo and Tobgay (2015) evaluated potential claims causing the delays and cost overruns of hydropower plant projects, applying descriptive statistics (i.e., percent frequency, bar charts, and pie charts) to find that adverse changes in geological conditions, changes in design and specification, owner delays in handing over the site, force majeure, and ambiguous contract provisions to be the critical causes involved. Sudirman and Hardjomuljadi (2012) also evaluated the potential risks of hydropower plant projects using the relative importance index (RII) method to find that adverse geological conditions, third-party delays, poor site management, slow decision making, and delays in site access were the significant project risks involved. Rebeiz (2012) studied potential risks in build-own-operate-transfer (BOOT) thermal power plant projects by qualitative research and identified the critical factors to be a loss of trust and loyalty, lack of skilled personnel, government interference, foreign currency fluctuations, change order disputes, unfamiliarity with technology, and labor unrest. Eybpoosh et al. (2011) presented SEM risk networks to understand the most important risk paths and their cost overrun influence in international power plant projects, finding that project risks have complex relationships. They identified 36 significant risk paths and discovered contractor-specific causes, such as fund shortages and inadequate technical and human resources to be the most critical risks involved.

From previous studies, 57 potential risks under nine groups have been identified as presented in Table 2.

Brief Overview of Fuzzy Risk Assessment Methods

Fuzzy logic was first introduced into construction risk assessment by Carr and Tah (2001), and since then, many researchers have applied or modified fuzzy logic in many different ways to increase its practicality (Islam et al. 2017). For example, modified fuzzy logic or fuzzy logic combined with such other methods as AHP, analytic network process (ANP), and technique for order of preference by similarity of ideal solution (TOPSIS) have received much attention for the risk assessment of power plant and linear infrastructure projects. Fuzzy-AHP, a popular multicriteria decision-making (MCDM) technique, is cumbersome for pairwise comparisons of risks in complex projects (Ebrahimnejad et al. 2012). ANP, a modified form of AHP, is suited to capturing the interdependencies between the risks and their effects (Zegordi et al. 2012). Like AHP, however, ANP also requires many tedious pairwise comparisons to be made. Fuzzy-TOPSIS is a popular MCDM method for project selection and risk assessment of complex projects under fuzzy environment. The method does not consider the correlation of attributes, and it is difficult to weight attributes and keep consistency of judgment (Velasquez and Hester 2013).

Table 1. Previous studies of power plant project risk assessment

References	Data collection	Method	Application area	Project
Xia et al. (2017)	Risk rating by five-point (1–5) Likert scale, questionnaire survey	Bayesian belief network	Lifecycle cost, risk analysis	Infrastructure (hydropower plant)
Liu et al. (2017)	Risk rating by five-point Likert scale, questionnaire survey	SEM	Design risk analysis	Power plant projects
Kucukali (2016)	Risk scoring by four-point scale (1–4), questionnaire survey	Weighted-sum multicriteria scoring	Revenue loss, risk assessment	Wind energy
Li and Wang (2016)	Risk rating by nine-point scale (1–9), structured interview	Fuzzy-AHP	Risk assessment	Power plant projects
Pall et al. (2016)	Previous literature	Content analysis, frequency ranking	Delay risk analysis	Power transmission
Yoo et al. (2017)	Risk rating by five-point Likert scale, questionnaire survey, pairwise comparison	TRS, RBS, ANP	Risk management	Nuclear power plant (NPP)
Hadikusumo and Tobgay (2015)	Studied project documents, archival records, and repots	Descriptive statistics	Claim analysis	Hydropower
Hossen et al. (2015)	Risk rating by nine-point Likert scale, questionnaire survey	AHP, RII	Delay risk assessment	NPP
Zhao and Li (2015)	Pairwise comparison, risk rating by nine-point scale, questionnaire survey, Delphi method	Fuzzy comprehensive evaluation (FCE), cloud model	Risk evaluation	UHV power transmission
Shafiee (2015)	Pairwise comparison, triangular fuzzy number (low, medium, high), structured interview	Fuzzy-ANP	Risk mitigation strategy selection	Wind power plant
Ji et al. (2015)	Risk evaluation by 11-point fuzzy number $(0, 0.1, -1)$	Fuzzy-entropy, TOPSIS	Risk assessment	Hydropower plant
Zegordi et al. (2012)	Risk rating by five-linguistic variable, questionnaire survey	Fuzzy-ANP, fuzzy-TOPSIS, RBS	Risk assessment	Power plant construction
Kucukali (2011)	Risk scoring by four-point scale (1–4), questionnaire survey	Fuzzy logic	Risk assessment	Hydropower plant
Rebeiz (2012)	Project's document study	Qualitative analysis	Risk management	Thermal power plant
Sudirman and Hardjomuljadi (2012)	Risk rating by five-point Likert scale, questionnaire survey, and interview	RII	Risk assessment	Hydropower plant
Ebrahimnejad et al. (2010)	Risk rating by seven-point scale, questionnaire survey	Fuzzy-TOPSIS, RBS	Risk assessment	Power plant projects
Dikmen et al. (2007)	Risk rating 1–10 scale, experts' judgment	Influence diagram, fuzzy logic	Risk assessment	Power plant projects
Eberhard and Gratwick (2007)	Interviews with experts	Inductive research approach	Risk identification	Power plant project

Note: ANP = analytic network process; and TOPSIS = technique for order of preference by similarity to ideal solution.

Table 2. Potential cost overrun risks of power plant projects

Group	Risk factors (code)	Hadikusumo and Tobgay (2015)	Eybpoosh et al. (2011)	Ke et al. (2010) and Wang and Tiong (2000)	Eberhard and Gratwick (2007)	Sudirman and Hardjomuljadi (2012)	Ebrahimnejad et al. (2010)	Rebeiz (2012)	Kucukali (2016)	Xia et al. (2017)	Li and Wang (2016)	Pall et al. (2016) and Liu et al. (2017)
Managerial	Poor feasibility study (Mg_1)	x	—	—	—	—	x	—	—	x	—	—
	Contractor's managerial weakness (Mg_2)	—	x	—	—	x	x	—	—	x	—	—
	Poor communication between the parties (Mg_3)	—	x	—	—	x	—	—	—	—	—	x
	Conflict between the project parties (Mg_4)	—	x	—	—	—	—	—	—	—	—	—
	Consultant's managerial weakness (Mg_5)	—	—	—	—	—	—	—	—	—	—	x
	Owner's incapable project manager (Mg_6)	—	—	—	—	—	—	—	—	—	—	x
Materials and equipment	Increased price of materials (ME_1)	—		x	—	—	—	—	—	—	—	—
	Shortage of equipment (ME_2)	—	—	—	—	—	—	—	—	—	—	x
	Delay by the suppliers in delivering plant/equipment at the site (ME_3)	—	x	—	—	x	—	x	—	—	—	x
	Construction equipment failure (ME_4)	—	—	—	—	—	—	—	—	—	—	—
	Failure of plant/equipment during installation (ME_5)	—	—	—	x	—	—	—	—	—	—	—
	Transportation difficulties (ME_6)	—	—	—	—	—	—	—	—	—	—	—
	Price fluctuations in the international market (demand-supply) (ME_7)	—	—	x	—	—	—	—	—	—	x	—
	Materials shortage (ME_8)	—	—	x	—	x	—	—	—	—	—	—
	New equipment/technology issues (ME_9)	—	—	—	—	—	—	—	—	x	x	—
	Unavailable in the local market (ME_{10})	—	—	—	—	—	—	—	—	—	—	x
Workforce	Lack of knowledge and experience (Mp_1)	—	x	—	—	x	—	—	—	—	—	—
	Labor shortage (Mp_2)	—	x	—	—	x	—	x	—	—	—	—
	Lack of skilled personnel (technical staff) on site (Mp_3)	—	x	—	—	—	—	x	—	—	—	—
Financial	Currency exchange rate (F_1)	—	—	x	—	x	—	x	—	—	x	—
	Bank interest rate (fluctuation/high) (F_2)	—	—	x	—	x	—	—	—	—	x	—
	Inflation (F_3)	—	—	x	—	x	—	—	—	x	x	—
	Owner's fund shortage and payment delays (govt.) (F_4)	—	—	—	—	—	x	—	—	x	x	—
	Multiple sources of funds (F_5)	—	—	—	—	—	x	—	—	—	—	—
	Contractor's fund shortage (F_6)	—	—	—		—	x	—	—	x	—	—
	Government policy (e.g., tax and incentives) (F_7)	—	—	—	x	—	—	—	—	—	x	—
	Poor finance management by contractor (F_8)	—	—	—	—	—	—	—	—	x	—	—
Project	Adverse change in geological conditions (P_1)	x	x	—	x	x	—	x	x	—	—	—
	Site constraints (P_2)	—	x				—		—	—	—	—
	Project complexity (P_3)		x				—	x	—	—	—	—

Table 2. (*Continued.*)

Group	Risk factors (code)	Hadikusumo and Tobgay (2015)	Eybpoosh et al. (2011)	Ke et al. (2010) and Wang and Tiong (2000)	Eberhard and Gratwick (2007)	Sudirman and Hardjomuljadi (2012)	Ebrahimnejad et al. (2010)	Rebeiz (2012)	Kucukali (2016)	Xia et al. (2017)	Li and Wang (2016)	Pall et al. (2016) and Liu et al. (2017)
Owner (government)	Site availability (P_4)	x		x		x	—	—	x	—	—	—
	Complex bureaucratic system (O_1)	—	—	—	—	—	—	—	—	x	—	—
	Delays in the project tendering process (O_2)	—	—	—	x	—	—	—	—	x	—	—
	Change orders during construction (O_3)	x	—	x	x	x	—	x	—	x	x	x
	Delays in decision making (O_4)	x	—	—	—	x	—	—	—	x	—	x
	Government customs policy and complexity (procurement delay) (O_5)	—	x	—	—	x	—	—	—	—	—	—
	Government interference in procurement (O_6)	—	—	—	—	—	—	—	—	x		—
	Delays in land acquisition (O_7)	—	—	—	—	x	—	—	—	x	—	x
	Utilities supply (O_8)	—	—	x	x	—	—	—	—	—	—	—
	Project approvals and permit delays (O_9)	—	—	x	x	—	—	—	—	x	—	—
	Lowest bidder selection (O_{10})	—	—	—	—	—	—	—	—	—	—	—
Contractor	Lack of knowledge and experience (Cn_1)	—	x	x	—	—	—	x	—	—	—	—
	Procurement delays (Cn_2)	—	x	—	—	—	x	—	—	—	—	—
	Delays in decision making (Cn_3)	x	—	—	—	x	—	—	—	—	—	—
	Subcontractor delays from preceding work (Cn_4)	x	—	—	—	—	—	x	—	—	—	—
	Improper finance management (Cn_5)	—	—	—	—	—	—	—	—	x	—	—
	Site safety (Cn_6)	—	x	x	—	x	—	x	—	x	—	—
	Construction (defect) quality (Cn_7)	—	x	x	—	x	—	—	—	—	—	—
	Poor planning and scheduling (Cn_8)	—	—	—	—	—	—	—	—	—	—	x
Consultant	Lack of knowledge and experience (Cs_1)	—	x	—	—	—	—	—	—	—	—	x
	Improper design/design errors (Cs_2)	—	x	x	—	—	—	x	—	x	—	x
	Delays in delivering design (Cs_3)	—	x			x	—	—	—	—	—	x
	Change of equipment, or specification of equipment, during construction (Cs_4)	x	—	—	—	—	—	—	—	—	—	x
Environment	Bad weather (heavy rain, wind, heat, and cold) or force majeure (E_1)	x	x	x	x	x	x	—	x	x	x	x
	Unusual flooding (E_2)	x	—	—	—	x	—	—	—	—	—	—
	Unexpected casualties/injuries (E_3)	x	—	—	—	x	—	x	—	—	—	—
	Environment preservation law (E_4)	—	—	x	—	—	—	—	x	x	x	—

Fuzzy methods in general also have other limitations. Novak (2012) has emphasized the need for considering the vagueness and uncertainty associated with the qualitative judgment of experts lacking adequate knowledge and relevant experience, as well as finding appropriate linguistic expressions for risk evaluation and suitable aggregation rules for quantifying the linguistic expressions for risk rankings. Rather than evaluating risks based solely on two criteria—probability (risk likelihood) and impact (consequence of the risk on project objectives)—the application of a fuzzy method for power plant project risk assessment should provide more reliable outcomes by including such parameters as the experts' experience/qualifications, project characteristics (Taroun 2014), phase-based risk identification and assessment, and consistency analysis (Borgonovo 2006).

Research Methodology

Fuzzy Group Decision-Making Approach

Risk assessment of complex projects is critical because of the complexity involved in understanding the nature of the risks, handling expert evaluations of risks and associated subjective biases, as well as the suitability of the chosen risk assessment method. Here, modified FGDMA after Tavakkoli-Moghaddam et al. (2011) is used. This involves experts evaluating risks by following the most commonly used probability-impact (P-I) approach (Taroun 2014), and by considering the risk detection level by work breakdown structure (WBS), i.e., identifying the risks in different project phases. The method also considers the judgmental ability of experts based on their professional competence (Jung et al. 2016) to evaluate individual risks and the factors shown to increase the reliability of decision making (Kabir et al. 2015). Also included is a consistency analysis of the elicited data by chi-square test and Cronbach's alpha test.

In the proposed FGDMA approach, the potential risks in different phases of power plant projects are selected, and experts' judgments are then elicited to evaluate the project risks. The experts provide judgments following the linguistic terms of none, very low, low, medium, high, very high, and extreme, with corresponding numerical values of 0, 1, 2, 3, 4, 5, and 6, respectively, to evaluate the individual risk in terms of risk likelihood and consequence as cost impact (Li and Wang 2016).

The step-by-step procedure of FGDMA is as follows:

1. The fuzzy triangular number (FTN) for the corresponding linguistic term is extracted following the scenario and description in Table 3. Triangular fuzzy numbers give particularly useful risk information for decision makers because they provide a three-point estimate (i.e., 0.5, 0.7, 0.9) rather than crisp risk values. It provides the flexibility to adopt appropriate risk management strategies for project execution phases.
2. Using the FTN, a fuzzy decision matrix (FDM) for risk likelihood (RL) or consequence (C) of individual risk (r) in a project phase (p) is formed by the following equation:

$$(\mathbf{FDM}^r_{\mathrm{RL}/C})_p = \begin{bmatrix} l_1 & m_1 & u_1 \\ \vdots & \ddots & \vdots \\ l_n & m_n & u_n \end{bmatrix} \tag{1}$$

where l, m, and u = low, medium, and upper values of risk likelihood or consequence of a risk, respectively; and n = number of domain experts evaluating the risks.
3. The experts' judgments of a particular phenomenon (and hence their reliability) vary for a number of reasons and thus need to be weighted accordingly. These are a function of their professional position (PP), working experience (EP), experience gained working on other projects (EO), and academic qualifications (AQ), which are collectively termed as professional competence (Jung et al. 2016). The level of professional competence of an individual expert needs to be incorporated into the risk analysis to increase data reliability (Kabir et al. 2015). The weight of professional competence of an expert (w_i^{Ind}) can be computed by (Aboshady et al. 2013):

$$w_i^{\mathrm{Ind}} = (w_{\mathrm{PP}} + w_{\mathrm{EP}} + w_{\mathrm{EO}} + w_{\mathrm{AQ}})_i \tag{2}$$

To evaluate the professional competence of the experts, the criteria weights (i.e., w_{PP}, w_{EP}, w_{EO}, and w_{AQ}) are assumed equal. The global weight of the professional competence of an expert (w_i^g) is calculated by (Ameyaw et al. 2015)

$$w_i^g = \frac{w_i^{\mathrm{Ind}}}{\sum_{i=1}^n w_i^{\mathrm{Ind}}}; \qquad \sum_{i=1}^n w_i^g = 1 \tag{3}$$

Here, as indicated in Table 3 (Jung et al. 2016), the global weights of all the experts must sum to unity to satisfy the condition that the highest level of the fuzzy score is 1.
4. The FDM for individual risk (r) of a project phase (p) is transformed into a weighted FDM (WFDM) by

Table 3. Linguistic variables and corresponding fuzzy numbers

Level of risk likelihood/consequence	Fuzzy triangular number (FTN)	Defuzzified number range	Description
Extremely high	0.9, 1.0, 1.0	0.90 to 1.00	Almost certain level of chance that the risk event will occur, and extremely significant for cost overrun
Very high	0.7, 0.9, 1.0	0.70 to <0.90	Very high chance of the risk event occurring, and most significant for cost overrun
High	0.5, 0.7, 0.9	0.50 to <0.70	High chance of risk event occurring, and significant value added to cost overrun
Medium	0.3, 0.5, 0.7	0.30 to <0.50	Likely chance of the risk event occurring, and moderately significant for cost overrun
Low	0.1, 0.3, 0.5	0.10 to <0.30	Rare chance of the risk event occurring, and little significant to cost overrun
Very low	0, 0.1, 0.3	0.025 to <0.10	Very rare chance of the risk event occurring, and very little significance to cost overrun
None	0, 0, 0.1	0 to <0.025	Risk event will never happen, and no significance to cost overrun

$$(\mathbf{WFDM}^r_{\mathrm{RL}/C})_p = (\mathbf{FDM}^r_{\mathrm{RL}/C})_p \times w_i^g$$

$$= \begin{bmatrix} l_1 & m_1 & u_1 \\ \vdots & \ddots & \vdots \\ l_n & m_n & u_n \end{bmatrix} (.\mathrm{x}) \begin{bmatrix} w_1^g \\ \cdots \\ w_n^g \end{bmatrix}$$

$$= \begin{bmatrix} l_1 w_1^g & m_1 w_1^g & u_1 w_1^g \\ \vdots & \ddots & \vdots \\ l_n w_n^g & m_n w_n^g & u_n w_n^g \end{bmatrix} \quad (4)$$

5. The fuzzy score (FS) for risk likelihood (RL) or consequence (C) of a project phase is computed by the sum of the individual columns of the [Eq. (4)] matrix by

$$(\mathbf{FS}^r_{\mathrm{RL}/C})_p = \left[\sum_{i=1}^n l_i w_i^g, \sum_{i=1}^n m_i w_i^g, \sum_{i=1}^n u_i w_i^g \right] \quad (5)$$

6. For the risk propagating through different project phases, the fuzzy score for the likelihood or consequence of that risk is

$$(\mathbf{FS}^r_{\mathrm{RL}/C})_P = \left(\sum_{p=1}^n w_p (\mathrm{FS}^r_{\mathrm{RL}/C})_p \right)_{L,M,U} \quad (6)$$

where L, M, and U = low, medium, and high scores of the risk likelihood or consequence of a risk in the project lifecycle (P); and w_p = weight of an individual project phase. Assigning equal weights to a risk that occurs in different project phases, or a failure to consider the importance of the different project phases, is considered a limitation of the current risk assessment process (Abdelgawad and Fayek 2010). However, it is challenging to assign weights for specific project phases. The parametric cost estimation of a combined-cycle power plant (CCPP) project showed that 70%–80% of project cost belongs to the design and procurement phase (Ministry of Finance, Malaysia 2016), and Tavakkoli-Moghaddam et al. (2011) claimed that almost 30% of risks originate from the construction phase, with the remainder belonging to the initial phases. In this study, therefore, 0.70 and 0.30 were assumed for w_p for the design and procurement phase, and construction and commissioning phase, respectively.

7. The fuzzy risk score (calculated by risk likelihood and consequence) is calculated by Eq. (7) and is adapted from the fuzzy synthetic evaluation approach for risk assessment of Xu et al. (2010)

$$(\mathbf{FRS}_r)_{L,M,U} = \left(\sqrt{(\mathbf{FS}^r_{\mathrm{RL}})_P \times (\mathbf{FS}^r_C)_P} \right)_{L,M,U} \quad (7)$$

where $(\mathbf{FS}^r_{\mathrm{RL}})_p$ and $(\mathbf{FS}^r_C)_p$ = fuzzy scores for risk likelihood and consequence, respectively, for the individual project phase (p) or whole project (P). The fuzzy method makes inferences of risks based on risk likelihood and consequence and by applying conventional fuzzy if-then rules. However, fuzzy if-then rules have been criticized for their inability to deal with subjective biases (Novak 2012), which prompts us to use an alternative technique suggested by Xu et al. (2010).

8. Defuzzification is required to define the risk level (i.e., very low to extreme) and follows (Abdelgawad and Fayek 2010)

$$f(x_i) = (\mathbf{FRS}_r)_{\mathrm{Deff.}} = \frac{(\mathbf{FRS}_r)_L + 4 * (\mathbf{FRS}_r)_M + (\mathbf{FRS}_r)_U}{6} \quad (8)$$

The whole process can be used to find the fuzzy risk score of a single phase, or the whole project, to evaluate the risk level (i.e., very low to extreme) of an individual risk, group risks, or project risk.

9. The risk score of a group of risks ($\mathbf{RSG}_a$) is calculated by the average of the risk scores (Jarkas et al. 2014), with

$$\text{Individual group's weight, } \mathbf{RSG}_a^{\mathrm{Ind}} = \frac{1}{m} \sum_{r=1}^m (\mathbf{FRS}_r)_{\mathrm{Deff.}} \quad (9)$$

$$\text{Global weight of a group}(\%), \mathbf{RSG}_a^g = \frac{\mathbf{RSG}_a^{\mathrm{Ind}}}{\sum_{a=1}^n \mathbf{RSG}_a^{\mathrm{Ind}}} \times 100; \quad \sum_{a=1}^n \mathbf{RSG}_a^g = 1 \quad (10)$$

where m = number of risks in a group; and n = number of group risks used for the project risk assessment.

10. The project risk level is computed as the mean of the defuzzified scores of the group risks involved, following Jarkas et al. (2014)

$$\text{Project risk score (PRS)} = \frac{\sum_{a=1}^n \mathbf{RSG}_a^{\mathrm{Ind}}}{n} \quad (11)$$

Eliciting Experts' Judgments

The literature suggests expert judgment to be the principal source of data being used for power plant project risk assessment. As highlighted in Table 1, previous studies frequently used a Likert scale for risk evaluation by eliciting expert judgment. However, there is some variation among risk evaluation scales (e.g., four-, seven-, nine-point scales). Here, a seven-point scale was used to elicit the expert judgment following a most relevant study (Ebrahimnejad et al. 2010), which used fuzzy-TOPSIS for power plant project risk assessment. The list of the risks in Table 2 was provided to the experts with opportunities to make any comments regarding any cost overrun risks that might not have been explicitly captured in the list. They evaluated the risk frequency/likelihood and consequence on a linguistic scale from 0 (none) to 6 (extremely high). They evaluated the risks in two major phases [i.e., (1) design and procurement, and (2) construction and commissioning] of power plant projects in terms of cost impact, a common parameter for risk evaluation criteria. This follows Taroun (2014), who suggested using a common measure for evaluating risks with the MCDM approach. The experts were also asked to provide their basic personal information (i.e., professional position, working experience, and academic qualifications) to find their professional competence levels, and the information regarding project characteristics (i.e., project ownership, plant type based on energy source, power generation capacity, and type of contract) for project-based risk scenario analysis.

The experts were selected based on their experience and professional position. The power plant projects were selected such that they represent the overall risk scenario of power plant construction projects and the industry. Questionnaires were hand-delivered to 100 experts from 20 randomly selected fully or partially completed power plant projects. A total of 70 experts, representing 15 power plant projects, returned the completed questionnaires. The majority hold a position of project directors and managers, with the remaining identifying themselves as project engineers and supervisors. Most of the fuzzy-based risk assessment studies (Table 1) elicited the judgments of approximately 50 experts, who were working in different levels of project management having proper knowledge

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and experience. Thus, the judgments of the 70 experts in this study are sound enough to make knowledge-based inferences using the proposed fuzzy approach.

The domain experts were selected from Bangladesh, a densely populated, fast-growing developing country in South Asia where power demand is projected to be 34,000 MW by 2030 and will be mainly based on natural gas, coal, and heavy fuel oil (HFO) thermal power plants, the delivery of is expected to cost approximately USD 70.5 billion (Bangladesh Country Commercial Guide 2017). Different major international organizations, such as the World Bank, Asian Development Bank, International Finance Corporation, and Japan International Cooperation Agency (JICA), have heavily invested (close to 70% of the finance), and many international construction companies from Asia, Europe, and the United States are involved in the construction of the power plant projects in Bangladesh (BPDB 2017). Currently, the country has commenced 32 megaprojects with a targeted production capacity of 11,209 MW, and 30 more projects of 4,909 MW capacity are now in the procurement phase. These 62 projects are expected to be completed by 2021 (BPDB 2017). However, previous projects have experienced serious cost overruns (e.g., 150%–200%) (Hannan 2015; Kabir 2012).

Consistency Analysis

The consistency analysis shows whether a significant difference exists among domain experts in evaluating project risks. The differences in judgments can be the result of a knowledge gap, judgment ability and bias, vague understanding of the project's uncertainty, and varying project contexts. The need for a suitable data consistency analysis, the one-sample chi-square test, in this case, stems from the study using categorical or ordinal data (i.e., data elicited from the experts using linguistic variables) to evaluate the cost overrun risks (Ke et al. 2010). If the chi-square test indicates that significant differences exist in the experts' judgments, the fuzzy-Delphi technique could be used to consolidate different experts' opinions where there is a vague understanding and limited knowledge and experiences of the experts (Nasirzadeh et al. 2014). However, if the judgment differences are the result of varying project contexts (e.g., project types, sizes, contracting systems, and project locations), then project-based risk analysis is appropriate for a comprehensive understanding of the cost overruns.

With the chi-square test, the null hypothesis (H_0) means that the experts' judgments are not equal to each other in evaluating a particular risk, and the significance level (α-value) is set to the conventional 0.05 for testing significance. Therefore, an α-value less than 0.05 means the null hypothesis is rejected, i.e., the experts' judgments are consistent with the risk evaluation. This study conducted a chi-square test of the potential risks in the design and procurement phase because it is the most influential phase of power plant projects (Ministry of Finance, Malaysia 2016), and the test results are presented in Table 4. The analysis results indicate that, with only a few exceptions, the experts were very consistent in evaluating the risks. Because the risk data were collected from the experts having different levels of professional competence and from the different types and sizes of power plant projects, the inconsistencies (i.e., H_0 retained) in few risks could be the effect of these differences. This result guided the project-based risk scenario analysis ("Results and Discussion" section) for a comprehensive understanding of the cost overruns involved. However, Cronbach's alpha test, which examines the internal consistency or reliability of Likert-scale data (Ghoddousi and Hosseini 2012), showed that internal consistency was generally good for risk likelihood evaluation and excellent for risk consequence evaluation (Table 4).

Table 4. Consistency analysis of the experts' judgments of risk evaluation in the design and procurement phase of the power plant projects

Risk	Asymptotic significance (α-value) Likelihood	Comment (H_0)	Consequence	Comment (H_0)
Mg_1	0.001	Rejected	0.039	Rejected
Mg_2	0.000	Rejected	0.000	Rejected
Mg_3	0.000	Rejected	0.100	Retained
Mg_4	0.003	Rejected	0.003	Rejected
Mg_5	0.000	Rejected	0.000	Rejected
Mg_6	0.003	Rejected	0.093	Retained
F_2	0.000	Rejected	0.022	Rejected
F_3	0.002	Rejected	0.100	Retained
F_4	0.054	Retained	0.008	Rejected
F_5	0.021	Rejected	0.048	Rejected
F_6	0.045	Rejected	0.017	Rejected
F_8	0.002	Rejected	0.236	Retained
P_2	0.011	Rejected	0.000	Rejected
P_3	0.000	Rejected	0.020	Rejected
O_1	0.078	Retained	0.001	Rejected
O_2	0.074	Retained	0.000	Rejected
O_3	0.020	Rejected	0.000	Rejected
O_4	0.006	Rejected	0.004	Rejected
O_5	0.015	Rejected	0.163	Retained
O_6	0.116	Retained	0.019	Rejected
O_{10}	0.000	Rejected	0.000	Rejected
Cn_1	0.003	Rejected	0.101	Rejected
Cn_2	0.000	Rejected	0.154	Retained
Cn_3	0.000	Rejected	0.000	Rejected
Cn_8	0.000	Rejected	0.046	Rejected
Cs_1	0.000	Rejected	0.071	Retained
Cs_2	0.000	Rejected	0.003	Rejected
Cs_3	0.021	Rejected	0.210	Retained
Cs_4	0.000	Rejected	0.077	Retained
ME_2	0.000	Rejected	0.001	Rejected
ME_3	0.000	Rejected	0.008	Rejected
ME_6	0.000	Rejected	0.000	Rejected
ME_7	0.030	Rejected	0.000	Rejected
ME_9	0.087	Retained	0.060	Retained
ME_{10}	0.085	Retained	0.143	Retained
Mp_2	0.010	Rejected	0.012	Rejected
Mp_3	0.000	Rejected	0.000	Rejected
Cronbach's alpha (internal consistency)	0.869 (good)	—	0.938 (excellent)	—

Results and Discussion

Overall Risk Scenario

Table 5 shows the overall risk scenario found using Eqs. (1)–(8). This represents the risk levels (likelihood, consequence as cost impact, and overall risks) in different project phases. Due to space limitations, only 35 important risks are shown; these are their defuzzified scores instead of triangular fuzzy numbers. This study is limited to two broad project phases of (1) design and procurement, and (2) construction and commissioning. The risks identified as causing the most significant power plant projects cost overruns are therefore the owner's complex bureaucratic system (O_1), delays in land acquisition (O_7), delays in the project tendering process (O_2), delays in decision making (O_4), and unavailability of materials and equipment in the local market (ME_{10}); these have high-level risks, with defuzzified scores in the range of 0.5 to 0.70.

Interestingly, mostly owner-related risks (i.e., top four risks in Table 5) are high level, and they are frequently encountered risks in

Table 5. Risk scenarios in different project phases (defuzzified scores)

Risk	Design and procurement						Construction and commissioning						Project level						
	Likelihood		Consequence		Risk		Likelihood		Consequence		Risk		Likelihood		Consequence		Risk		
code	Score	Level	Score	Level	Score	Level	Score	Level	Score	Level	Score	Level	Score	Level	Score	Level	Score	Level	Rank
O_1	0.605	H	0.623	H	0.614	H	—	—	—	—	—	—	0.605	H	0.623	H	0.614	H	1
O_7	—	—	—	—	—	—	0.613	H	0.596	H	0.604	H	0.613	H	0.596	H	0.604	H	2
O_2	0.542	H	0.56	H	0.551	H	—	—	—	—	—	—	0.542	H	0.56	H	0.551	H	3
O_4	0.479	M	0.556	H	0.516	H	0.477	M	0.539	H	0.507	H	0.479	M	0.552	H	0.514	H	4
ME_{10}	0.523	H	0.481	M	0.502	H	0.505	H	0.489	M	0.497	M	0.52	H	0.483	M	0.501	H	5
O_{10}	0.509	H	0.457	M	0.482	M	0.513	H	0.522	H	0.518	H	0.51	H	0.47	M	0.49	M	6
Cn_8	0.451	M	0.518	H	0.483	M	0.469	M	0.560	H	0.512	H	0.455	M	0.525	H	0.489	M	7
Cn_3	0.433	M	0.552	H	0.489	M	0.417	M	0.52	H	0.466	M	0.43	M	0.545	H	0.484	M	8
O_5	0.484	M	0.492	M	0.488	M	0.428	M	0.459	M	0.443	M	0.473	M	0.486	M	0.479	M	9
Cs_1	0.444	M	0.523	H	0.482	M	0.431	M	0.492	M	0.46	M	0.441	M	0.517	H	0.477	M	10
O_3	0.484	M	0.473	M	0.478	M	0.445	M	0.453	M	0.449	M	0.476	M	0.469	M	0.472	M	11
Mg_2	0.445	M	0.478	M	0.461	M	0.45	M	0.521	H	0.484	M	0.446	M	0.487	M	0.466	M	12
Cn_1	0.427	M	0.501	H	0.462	M	0.418	M	0.51	H	0.462	M	0.425	M	0.502	H	0.462	M	13
Cn_2	—	—	—	—	—	—	0.403	M	0.522	H	0.459	M	0.403	M	0.522	H	0.459	M	14
P_2	0.450	M	0.459	M	0.454	M	0.459	M	0.472	M	0.465	M	0.452	M	0.461	M	0.457	M	15
F_8	0.429	M	0.473	M	0.451	M	0.442	M	0.475	M	0.458	M	0.432	M	0.473	M	0.452	M	16
F_6	0.418	M	0.482	M	0.449	M	0.407	M	0.489	M	0.446	M	0.416	M	0.484	M	0.448	M	17
Mp_3	—	—	—	—	—	—	0.43	M	0.466	M	0.447	M	0.43	M	0.466	M	0.447	M	18
P_3	0.418	M	0.478	M	0.447	M	0.415	M	0.456	M	0.435	M	0.417	M	0.473	M	0.444	M	19
Mg_1	0.396	M	0.503	H	0.446	M	0.393	M	0.452	M	0.421	M	0.395	M	0.492	M	0.441	M	20
Mg_6	0.362	M	0.541	H	0.442	M	0.357	M	0.512	H	0.428	M	0.361	M	0.535	H	0.439	M	21
F_2	0.416	M	0.464	M	0.439	M	0.423	M	0.458	M	0.44	M	0.417	M	0.462	M	0.439	M	22
Mp_1	0.386	M	0.454	M	0.419	M	0.431	M	0.481	M	0.455	M	0.395	M	0.46	M	0.426	M	23
Cs_2	0.386	M	0.473	M	0.427	M	0.356	M	0.459	M	0.404	M	0.38	M	0.47	M	0.422	M	24
Mp_2	—	—	—	—	—	—	0.397	M	0.432	M	0.414	M	0.397	M	0.432	M	0.414	M	25
F_4	0.393	M	0.431	M	0.412	M	0.374	M	0.442	M	0.406	M	0.389	M	0.433	M	0.411	M	26
ME_6	0.385	M	0.423	M	0.404	M	0.42	M	0.446	M	0.433	M	0.392	M	0.428	M	0.409	M	27
ME_2	—	—	—	—	—	—	0.378	M	0.443	M	0.409	M	0.378	M	0.443	M	0.409	M	28
O_6	0.390	M	0.416	M	0.403	M	0.348	M	0.374	M	0.361	L	0.382	M	0.408	M	0.395	M	29
Mg_4	0.370	M	0.405	M	0.387	M	0.387	M	0.449	M	0.417	M	0.374	M	0.414	M	0.393	M	30
Mg_3	0.337	M	0.434	M	0.382	M	0.36	M	0.448	M	0.402	M	0.342	M	0.437	M	0.386	M	31
ME_3	0.342	M	0.373	M	0.357	M	0.424	M	0.484	M	0.453	M	0.358	M	0.395	M	0.376	M	32
Cs_4	0.303	M	0.394	M	0.345	M	0.355	M	0.437	M	0.394	M	0.313	M	0.403	M	0.355	M	33
Cs_3	—	—	—	—	—	—	0.325	M	0.368	M	0.346	M	0.325	M	0.368	M	0.346	M	34
F_3	0.326	M	0.346	M	0.336	M	0.312	M	0.328	M	0.32	M	0.324	M	0.343	M	0.333	M	35

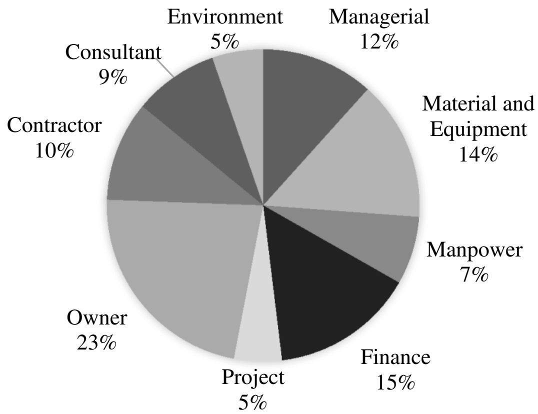

Fig. 1. Risk contribution by different group risks.

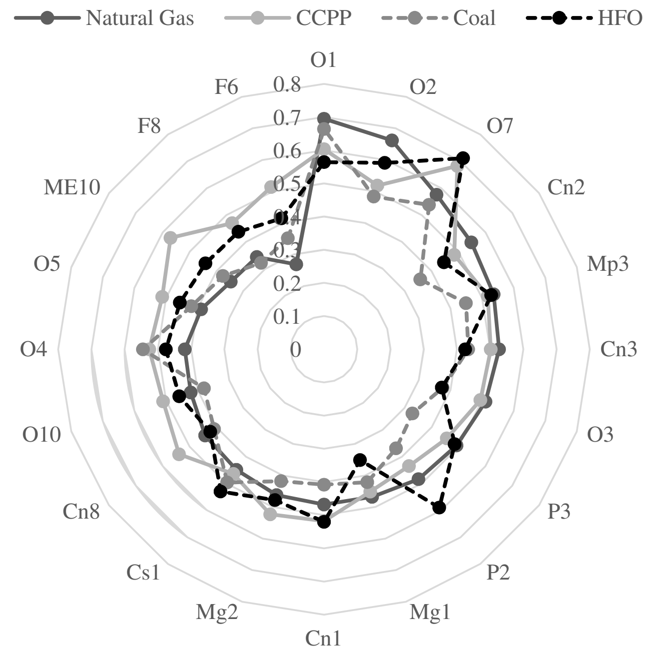

Fig. 2. Comparative risks scenarios of different power plant projects.

design and procurement phase. According to Table 3, these high-level risks can be defined as triangular fuzzy number i.e., 0.5, 0.7, and 0.9, and interpreted, respectively, as follows: the risks could have (1) a high chance of occurrence and cause significant cost impact, (2) a very high chance of occurrence and most significant values added to cost overrun, and (3) almost certain chance to occur and extremely significant values added to cost overrun. The other remaining risks are identified as medium-level risks having likely chance of occurrence and with a moderately significant impact on cost overrun. Of these, the prevalent practice of selecting bidders solely based on cost by the owner (O_{10}), poor planning and scheduling (Cn_8), delays in decision making by the contractor (Cn_3), government customs policy and complexity of procurement (O_5), and a consultant's lack of knowledge and experience (Cs_1) are particularly relevant.

Fig. 1 shows the different risk groups and their contribution to cost overruns, from Eqs. (9) and (10). The owner, finance, and materials and equipment risk groups contribute more than 50% of project risks. The other three groups (managerial, contractor, and consultant) collectively account for 31% of cost overruns. Within the groups, owner-related risks are responsible for almost a quarter (23%) of the causes of cost overruns, whereas environment-related risks have the lowest overall contribution (5%). Furthermore, 10 owner-related risks are identified from the literature, eight of which (i.e., O_1, O_7, O_2, O_4, O_{10}, O_5, O_3, and O_6) are listed in Table 5 as important cost overrun risks. This increases the percent contribution of this group to the overall cost overrun (Fig. 1). Managerial risks also contribute significantly, with five out of six risks identified from the literature (Table 5) having a moderately significant impact.

Project-Based Risk Scenario

Fig. 2 shows the comparative risk scenario of different power plant projects based on the 20 top-ranked risks. The result indicates that the risk scenario varies with project types (i.e., energy sources). The complex bureaucratic system (O_1) is a high-risk factor for all types of projects; land acquisition (O_7) is a very high risk for HFO and high for the other three types, and lowest bidder selection (O_{10}) is medium. A total of 14 risks are identified as high-level risk (defuzzified score above 0.50) in CCPP projects, followed by seven risks in HFO and natural gas (NG), and three risks in coal-based projects. Thus, CCPP projects are recognized as high-risk projects because they have risk score over 0.50, and all other projects are medium-risk projects (i.e., risk score of 0.30–0.50). This result indicates that CCPP project cost overrun is at a significant level compared with other projects. HFO and natural gas projects have a similar risk level at 0.485 and 0.475, respectively, which is slightly higher than coal projects (i.e., 0.427).

The 10 different project scenarios were then used to better understand the context of project risks and their profile by examining contract (procurement) type [engineering-procure-construct (EPC) versus turnkey], project size/capacity (in MW), and type of energy source used. The few private and PPP projects in the database were excluded from the analysis due to their low representation. Table 6 presents the results, which indicate that the risk-levels of natural gas projects are reduced with a change in contract type—in this case from EPC to turnkey. This could be due to the significant reduction in some of the more notable risks: complex bureaucratic system (O_1), delays in the project tendering process (O_2), site constraints (P_2), change orders (O_3), and contractors' lack of knowledge and experience (Cn_1). Moreover, large coal projects (i.e., 300 MW or above) are less exposed to risks, even within the same EPC type of contracting, with low risk-scores (<0.30) for changes order during construction (O_3), project complexity (P_3), procurement delay (Cn_2), and planning and scheduling (Cn_8). However, project size and contract type were not the significant factors influencing HFO risk levels because all their risk-scores are approximately 0.4, and CCPP, where all risk-scores are approximately 0.5.

Discussion of Important Risks

The application of FGDMA to cost overrun risk assessment of thermal power plant projects in Bangladesh has revealed a number of insights. Owner-related risks are mostly to blame for cost overruns. Of particular interest is the presence of the owner's (government) complex bureaucratic system, which confirms the findings of Xia et al. (2017) for power plant risks in China. In Bangladesh, the requirement for any new project is such that the Bangladesh Power Development Board (BPDB) initially presents a development project proposal (DPP) with the estimated cost, project benefits, and constraints to the Ministry of Planning (MoP). In order to obtain

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Table 6. Project variables-based risk scenarios (defuzzified scores)

	Public projects										
	EPC							Turnkey			
	100–200 MW			200–300 MW		300 MW and above		100–200 MW	300 MW and above		Mean score
Risk	NG	HFO	CCPP	CCPP	Coal	CCPP	Coal	HFO	NG	CCPP	
O_1	0.72	0.57	0.66	0.51	0.77	0.62	0.58	0.7	0	0.7	0.58
O_7	0	0.71	0.75	0.51	0.57	0.64	0.48	0.66	0.3	0.66	0.53
O_2	0.72	0.55	0.61	0.51	0.66	0.52	0.36	0.64	0	0.5	0.51
ME_{10}	**0.18**	0.42	0.56	0.6	0.46	0.57	0.311	0.59	**0.83**	0.43	0.50
O_4	0.26	0.45	0.57	0.41	0.7	0.54	0.43	0.44	0.3	0.71	0.48
P_3	0.67	0.36	0.41	0.47	0.7	0.4	***0.16***	0.61	0.5	0.5	0.48
Cs_1	0.38	0.58	0.55	0.49	0.69	0.44	0.35	0.59	0.3	0.39	0.48
O_5	0.53	0.47	0.5	0.51	**0.59**	0.52	**0.3**	0.32	**0.61**	0.4	0.48
P_2	0.59	0.4	0.52	0.47	0.5	0.45	0.31	0.5	0.3	0.7	0.47
Cn_2	0.67	0.36	0.48	0.54	0.62	0.45	***0.17***	0.42	**0.59**	0.39	0.47
Mg_1	0.49	0.37	0.48	0.49	0.55	0.43	0.33	0.54	**0.53**	0.33	0.45
Mg_2	0.52	0.45	0.48	0.48	0.34	0.54	0.47	0.32	0.4	0.37	0.44
Cn_1	0.57	0.42	0.41	0.41	0.41	0.6	0.2	0.5	0.3	0.55	0.44
O_3	0.58	0.39	0.41	0.52	0.66	0.5	***0.17***	0.17	0	0.86	0.43
Mp_3	0.58	0.27	0.48	0.53	0.42	0.5	0.39	0.2	0.19	0.39	0.40
Cn_8	0.39	0.28	0.38	0.42	0.69	0.61	***0.2***	0.39	0	0.59	0.40
F_6	0.26	0.33	0.39	0.44	0.7	0.53	0.17	0.36	0.12	0.46	0.38
O_{10}	0	0.49	0.48	0.45	0.26	0.56	0.5	0.39	0	0.54	0.37
Cn_3	0.48	0.19	0.36	0.49	0.62	0.38	0.3	0.25	0	0.55	0.36
F_8	0.12	0.07	0.44	0.51	0.54	0.5	0.14	0.33	0.39	0.46	0.35
Mean score	0.44	0.41	**0.5**	**0.49**	**0.57**	**0.52**	0.32	0.45	0.28	**0.52**	0.45

Note: The bold and italic values for some risks were given to highlight the significant changes in risk-score because of applying the proposed model.

approval for a project, a guarantee for finance, cooperation with, and assistance from the MoP is critically important. The domain experts expressed their frustration with the complex bureaucratic system in the country for the protracted project approval and tendering processes involved. The project tendering process is also delayed due to a lack of cooperation among government departments, as well as a lack of interest from the donor agencies to finance the project (Eberhard and Gratwick 2007). Megaprojects often suffer a greatly in the tendering process and complying with associated formalities (Xia et al. 2017). It is not surprising, therefore, that a number of years can elapse before selecting contractors (Kabir 2012). Consequently, international market prices of equipment and materials can significantly increase, rendering the initial project budget insufficient.

The delay in land acquisition is a significant risk to project cost overruns and echoes studies in other countries (Sudirman and Hardjomuljadi 2012; Xia et al. 2017). The owner (or government entity) has sole responsibility for finding suitable land for the project, but many projects are delayed in reality. This prevents the contractors' access to the land, thereby incurring extra costs (Kucukali 2016) for sociopolitical reasons, for instance, unsettled land with the owner (Sudirman and Hardjomuljadi 2012), environmental issues, and lack of cooperation among government organizations (Kim et al. 2017). The availability of materials and equipment in the local market is also a major factor responsible for increasing project cost as a result of a delayed procurement process (Pall et al. 2016).

Existing customs policies, and more importantly, changes in customs policies such as imposing or waiving customs duty and value-added tax, can significantly impact the procurement of materials and equipment and thus the time and cost performance of a project (ADB 2013). Of course, the contractor could avoid this situation by having a more realistic procurement plan of long lead items (Eybpoosh et al. 2011), although doing so may jeopardize competitiveness to some extent. The contractor's poor planning and scheduling and delay in decision making in procurement and construction were also identified being significant risks for cost overruns (Hadikusumo and Tobgay 2015; Sudirman and Hardjomuljadi 2012). Akin to the studies in other developing countries such as Indonesia (Sudirman and Hardjomuljadi 2012), Iran (Ebrahimnejad et al. 2012), and China (Li and Wang 2016), contractor-related issues—managerial weakness, lack of knowledge and experience, poor finance management, and fund shortages—also contribute to cost overruns in power plant projects in Bangladesh.

The majority of power plant projects are constructed mainly through an EPC (i.e., engineering, procurement, and construction) type of contract (Kehlhofer et al. 2009), where the EPC contractor has sole responsibility for detail design and procurement based on the owner's requirements. In Bangladesh, usually, the lowest bidder is procured as the EPC contractor, which is identified as one of the major risk drivers to cost overruns in power plant projects. The lowest bid price tends to be awfully off-track from the realistic project cost (Ahiaga-Dagbui and Smith 2014). It is not uncommon that the lowest bidder in power plant and similar infrastructure projects recoup huge extra amounts through change orders in the project execution phase (Kim et al. 2017; Li and Wang 2016; Liu et al. 2017). This study found that owner-initiated change orders equally contributed to cost overruns and were mainly resulted from a poor feasibility study of the project, consultant's lack of knowledge and experience, and owner's additional requirements or changes in design specifications, findings similar to those of Han and Diekmann (2004).

Design errors, another common issue and significant risk factor to cause change order, delays the procurement and construction of the project because any design revision cycle in complex power plant projects takes a long time. Owner's delay in decision making and poor project management on the owner's part all the way from

Table 7. Sensitivity analysis of the FGDMA model

Risk code	Risk scores: Without expert weight	FGDMA	Change (%)	Without phase weight	FGDMA	Change (%)
O_1	0.549	0.614	***10.528***	0.614	0.614	0.000
O_7	0.594	0.604	1.581	0.621	0.604	2.815
O_2	0.492	0.551	***10.630***	0.551	0.551	0.000
O_4	0.492	0.514	4.270	0.503	0.514	2.130
ME_{10}	0.517	0.501	3.283	0.502	0.501	0.223
O_{10}	0.486	0.490	0.873	0.500	0.490	1.981
Cn_8	0.510	0.489	4.256	0.498	0.489	1.903
Cn_3	0.486	0.484	0.311	0.480	0.484	0.894
O_5	0.475	0.479	0.887	0.464	0.479	3.073
Cs_1	0.478	0.477	*0.161*	0.475	0.477	0.353
O_3	0.465	0.472	1.518	0.456	0.472	3.350
Mg_2	0.510	0.466	***9.456***	0.507	0.466	***8.843***
Cn_1	0.508	0.462	***9.892***	0.489	0.462	**5.747**
Cn_2	0.473	0.459	3.092	0.459	0.459	0.000
P_2	0.473	0.457	3.409	0.460	0.457	0.732

Note: The bold and italic values for some risks were given to highlight the significant changes in risk-score because of applying the proposed model.

project initiation to commissioning were also found to be critical factors in cost overruns. A proper risk identification and assessment at preliminary budgeting can assist for the development of more realistic risk response and mitigation strategies to reduce cost overruns in power plant projects.

Sensitivity Analysis

Sensitivity analysis is most commonly used for validating the knowledge-based approach because it is a powerful technique for examining the sensitivity of risk assessment models to individual risk factors (Gonzalez and Dankel 1993; Mokhtari et al., 2012). The sensitivity analysis also indicates the accuracy and reliability of the model's output to changes in input variables (Zaili et al. 2008). The FGDMA here introduced a weight for an expert's professional competence, as well as a weight for an individual project phase, to increase the accuracy of the risk assessment (Cooke 1991). However, this approach to computing risk scores based on subjective data has been criticized for as lacking in accuracy, particularly in the use of expert weights (Clemen 2008) in the risk assessment process. Therefore, a comparison of the findings with and without expert weights was undertaken by introducing different weightings for each project phase based on knowledge gathered from the literature. The results of the analyses for 15 top-ranked risks are presented in Table 7, indicating that the experts' weights have a significant impact on the risk-scores of some factors, with the highest (10.63%) amount of change being attributable to delays in the project tendering process (O_2). On the other hand, phase weight has relatively less impact on the risk-scores, except for such factors as contractor's managerial weakness (Mg_2) and lack of knowledge and experience (Cn_1).

Conclusion

This research investigated the potentially significant cost overrun risks to power plant projects, with a particular focus on fossil fuel–based thermal power plants, by proposing a knowledge-based fuzzy group decision-making approach. The FGDMA was modified by taking into account the professional competence of the experts as well as the project phases. A sensitivity analysis was conducted to evaluate the extent to which assigning a weight factor for the professional competence of the experts and project phase significantly affected the overall risk assessment outcome.

A number of risks were identified as significant in causing power plant project cost overruns. Notably, the complex bureaucracy within the host country's government, delays in land acquisition and project tendering processes, delays in decision making on behalf of the owner, and availability of material and equipment in the local market were identified as the most high-level risk factors involved. The group risks analysis showed that owner-related risks alone contribute almost a quarter of the total cost overruns; financial, materials and equipment, managerial, and contractor-related risks contribute significantly to cost overruns. The project-based risk analysis showed that the risk level varies with such project characteristics as project type, size, and contracting system, with CCPP projects encountering a higher risk exposure. The sensitivity analysis showed that using experts' weights has a significant impact on the outcome of individual risks, with delays in the project tendering process identified as the most sensitive.

This study contributes to the existing body of knowledge on risk management in several ways. It uniquely identifies the cost overrun risks and scenarios of different types of thermal power plant projects by applying a project phase–based risk analysis with due consideration of the various project characteristics (project type, size, and contract system) of thermal power plant projects. Project owners, project financiers, and contractors involved in fossil fuel–based thermal power plant projects will greatly benefit from this research. Prior to this study, limited empirical data were available for a comprehensive understanding and assessment of cost overrun risks involved in thermal power plant projects. The proposed modified FGDMA-based risk assessment approach significantly contributes to the existing risk management practice on power plant projects in that it improves the reliability of the risk assessment outcomes and advances the fuzzy-aggregation process of risk ranking. The approach can equally be applied for delay and cost overrun risks analyses of other similar infrastructure projects that have highly interrelated project phases, phase overlaps, multistage contracting systems, and sheer level of uncertainty.

The study results indicate that although certain risks are critical in different project phases, their risk levels vary significantly with project characteristics. It also shows that reduction of the risk levels of some major factors can be critical to reduce the overall project cost overrun risk. The outcome of this study will increase the accuracy of project budgeting and contingency allocation decisions and be of assistance to domain experts in proactively dealing with the risks and uncertainties involved in the execution phases of power plant projects.

Recommendations

Recommendations for Future Research

The current study examined two project phases: (1) design and procurement, and (2) construction and commissioning. Further research is needed into additional project phases to better understand the risks and their interrelationships from a whole-of-project perspective. Although the fuzzy method is appropriate for risk assessment involving subjective data, it has the limitation of only capturing the causal relationships between risks. The FGDMA approach combined with Bayesian belief networks (Islam et al. 2017) or a structural equation modeling (Eybpoosh et al. 2011) has further potential for modeling the complex risk networks involved and for conducting cause and effect analyses of the risks in power plant and similar infrastructure projects.

Recommendations to Industry Professionals

This study has provided insights regarding the sources of the critical cost overrun risks, their level of severity, and how they propagate from one project phase to another. The following recommendations are provided to major industry professionals (i.e., clients and the EPC contractors) based on the results of this study:

- The client needs to develop and/or hire a very skilled and experienced project management team, particularly a project manager, to identify, assess and manage risks from project inception through the commissioning of the project and to successfully deliver a project. An experienced and knowledgeable owner's consultant can support the client's project management team to develop clear project scope definition and design specifications.
- Changes in design and the specifications of major equipment should be managed through a proper change control management and contract administration system.
- The client needs a champion who is able to work with the relevant government bodies and donor agencies to reduce bureaucratic complexity and red tape for DPP approval and tendering.
- The client should conduct a thorough feasibility study of the planned site and work closely with relevant state land and the department of environment as well as with other stakeholders to minimize land acquisition delay. A database containing information on historical costs, past projects, and lessons learned would be valuable resource for client organizations for cost estimation and managing risks in DPP and tendering.
- Delay in DPP approval and land acquisition could be considered as a known delay from the lessons learned from previous projects. This delay can be adjusted in the budgets of future projects by developing a national construction cost index.
- There needs to be a more comprehensive assessment of contractors' pre-emptive qualification criteria [e.g., contractor's knowledge and experience, successful delivery record of similar projects, understanding project environment, resource availability, and risk/change management history (Aznar et al. 2017; Doloi 2009)] for contractors' selection and award.

Power plant projects in Bangladesh are normally done by EPC contractors. Some specific recommendations to contractors involved in power plants projects are as follows:

- The contractor's consultant should be very careful to minimize errors and discrepancies in the design documents because any major revisions of a design take a long time and causes a significant delay in both procurement and construction phases of a power plant project.
- It is critical for the contractor to prepare a proper risk management plan and develop a realistic bid price by risks and uncertainty analysis, informed largely by the similar previous projects in the host country.
- Care should be taken to make a realistic project plan and schedule for procurement and construction with due consideration for resource availability and site constraints. The plan and schedule will require continuous monitoring and updates.
- The contractor has to set up a proper cash-flow management plan and cost control system to manage project cost.
- In order to improve the managerial performance particularly on construction sites, the contractor needs to ensure that competent people with right skill sets and those who are familiar to the project site and working environment of the host country are assigned.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information about the *Journal*'s data-sharing policy can be found here: http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263.

References

Abdelgawad, M., and A. R. Fayek. 2010. "Risk management in the construction industry using combined fuzzy FMEA and fuzzy AHP." *J. Constr. Eng. Manage.* 136 (9): 1028–1036. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000210.

Aboshady, A. M., M. M. G. Elbarkouky, and M. Mohamed. 2013. "A fuzzy risk management framework for the Egyptian real estate development projects." In *Proc., Architectural Engineering Conf.*, 343–352. Reston, VA: ASCE.

ADB (Asian Development Bank). 2013. "Bangladesh: Power sector development program." Accessed February 10, 2016. http://www.adb.org/projects/36205-023/main.

Ahiaga-Dagbui, D. D., and S. D. Smith. 2014. "Rethinking construction cost overruns: Cognition, learning and estimation." *J. Finan. Manage. Prop. Const.* 19 (1): 38–54. https://doi.org/10.1108/JFMPC-06-2013-0027.

Ameyaw, E. E., A. P. C. Chan, O.-M. De-Graft, and E. Coleman. 2015. "A fuzzy model for evaluating risk impacts on variability between contract sum and final account in government-funded construction projects." *J. Facil. Manage.* 13 (1): 45–69. https://doi.org/10.1108/JFM-11-2013-0055.

Aznar, B., E. Pellicer, S. Davis, and P. Ballesteros-Pérez. 2017. "Factors affecting contractor's bidding success for international infrastructure projects in Australia." *J. Civ. Eng. Manage.* 23 (7): 880–889. https://doi.org/10.3846/13923730.2017.1341955.

Bangladesh Country Commercial Guide. 2017. "Bangladesh: Power & energy." Accessed October 5, 2017. https://www.export.gov/article?id=Bangladesh-Power-and-energy.

Borgonovo, E. 2006. "Measuring uncertainty importance: Investigation and comparison of alternative approaches." *Risk Anal.* 26 (5): 1349–1361. https://doi.org/10.1111/j.1539-6924.2006.00806.x.

BPDB (Bangladesh Power Development Board). 2017. "Annual report (2015–16)." Accessed October 5, 2017. http://www.bpdb.gov.bd/download/annual_report/Annual_Report_2015_16.pdf.

Carr, V., and J. H. Tah. 2001. "A fuzzy approach to construction project risk assessment and analysis: Construction project risk management system." *Adv. Eng. Soft.* 32 (10–11): 847–857. https://doi.org/10.1016/S0965-9978(01)00036-9.

Clemen, R. T. 2008. "Comments: Comment on Cooke's classical method." *Reliab. Eng. Syst. Saf.* 93 (5): 760–765. https://doi.org/10.1016/j.ress.2008.02.003.

Cooke, R. 1991. *Experts in uncertainty: Opinions and subjective probability in science*. New York: Oxford University Press.

Dikmen, I., M. T. Birgonul, and S. Han. 2007. "Using fuzzy risk assessment to rate cost overrun risk in international construction projects." *Int. J. Project Manage.* 25 (5): 494–505. https://doi.org/10.1016/j.ijproman.2006.12.002.

Doloi, H. 2009. "Analysis of pre-qualification criteria in contractor selection and their impacts on project success." *Constr. Manage. Econ.* 27 (12): 1245–1263. https://doi.org/10.1080/01446190903394541.

Eberhard, A., and K. Gratwick. 2007. "From state to market and back again: Egypt's experiment with independent power projects." *Energy* 32 (5): 724–738. https://doi.org/10.1016/j.energy.2006.05.003.

Ebrahimnejad, S., S. M. Mousavi, and H. Seyrafianpour. 2010. "Risk identification and assessment for build-operate–transfer projects: A fuzzy multi attribute decision making model." *Expert Syst. Appl.* 37 (1): 575–586. https://doi.org/10.1016/j.eswa.2009.05.037.

Ebrahimnejad, S., S. M. Mousavi, R. Tavakkoli-Moghaddam, H. Hashemi, and B. Vahdani. 2012. "A novel two-phase group decision making approach for construction project selection in a fuzzy environment." *Appl. Math. Model.* 36 (9): 4197–4217. https://doi.org/10.1016/j.apm.2011.11.050.

Eybpoosh, M., I. Dikmen, and M. T. Birgonul. 2011. "Identification of risk paths in international construction projects using structural equation modeling." *J. Constr. Eng. Manage.* 137 (12): 1164–1175. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000382.

Ghoddousi, P., and M. R. Hosseini. 2012. "A survey of the factors affecting the productivity of construction projects in Iran." *Technol. Econ. Dev. Economy* 18 (1): 99–116. https://doi.org/10.3846/20294913.2012.661203.

Gilbert, A., B. K. Sovacool, P. Johnstone, and A. Stirling. 2017. "Cost overruns and financial risk in the construction of nuclear power reactors: A critical appraisal." *Energy Policy* 102: 644–649. https://doi.org/10.1016/j.enpol.2016.04.001.

Gonzalez, A. J., and D. D. Dankel. 1993. *The engineering of knowledge-based systems: Theory and practice*. Englewood-Cliffs, NJ: Prentice-Hall.

Hadikusumo, B. H. W., and S. Tobgay. 2015. "Construction claim types and causes for a large-scale hydropower project in Bhutan." *J. Constr. Dev. Countries* 20 (1): 49–63.

Han, S. H., and J. Diekmann. 2004. "Judgment-based cross-impact method for predicting cost variance for highly uncertain projects." *J. Constr. Res.* 5 (2): 171–192. https://doi.org/10.1142/S1609945104000139.

Hannan, S. A. 2015. "Fate of 13 power plants hangs in balance: Serious efforts needed to solve the problems." *Khabor Dot Kom, Online Yahoo Group*, 1–3.

Hossen, M. M., S. Kang, and J. Kim. 2015. "Construction schedule delay risk assessment by using combined AHP-RII methodology for an international NPP project." *Nuclear Eng. Technol.* 47 (3): 362–379. https://doi.org/10.1016/j.net.2014.12.019.

Islam, M. S., M. P. Nepal, M. Skitmore, and M. Attarzadeh. 2017. "Current research trends and application areas of fuzzy and hybrid methods to the risk assessment of construction projects." *Adv. Eng. Info.* 33: 112–131. https://doi.org/10.1016/j.aei.2017.06.001.

Jarkas, A. M., S. A. Mubarak, and C. Y. Kadri. 2014. "Critical factors determining bid/no bid decisions of contractors in Qatar." *J. Manage. Eng.* 30 (4): 05014007. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000223.

Ji, Y., G. H. Huang, W. Sun. 2015. "Risk assessment of hydropower stations through an integrated fuzzy entropy-weight multiple criteria decision making method: A case study of the Xiangxi River." *Expert Syst. Appl.* 42 (12): 5380–5389. https://doi.org/10.1016/j.eswa.2014.12.026.

Jung, J. H., D. Y. Kim, and H. K. Lee. 2016. "The computer-based contingency estimation through analysis cost overrun risk of public construction project." *KSCE J. Civ. Eng.* 20 (4): 1119–1130. https://doi.org/10.1007/s12205-015-0184-8.

Kabir, G., R. Sadiq, and S. Tesfamariam. 2015. "A fuzzy Bayesian belief network for safety assessment of oil and gas pipelines." *Struct. Infrastruct. Eng.* 12 (8): 874–889. https://doi.org/10.1080/15732479.2015.1053093.

Kabir, H. 2012. "Delay, fund crisis plague large power plants implementation." *Financial Express* 20 (435), in press.

Ke, Y., S. Wang, A. P. C. Chan, and P. T. I. Lam. 2010. "Preferred risk allocation in China's public-private partnership (PPP) projects." *Int. J. Project Manage.* 28 (5): 482–492. https://doi.org/10.1016/j.ijproman.2009.08.007.

Kehlhofer, R., B. Rukes, F. Hannemann, and F. Stirnimann. 2009. "Economics." Chap. 3 in *Combined-cycle gas & steam turbine power plants*, 3rd ed., 13. Tulsa, OK: Pennwell Books.

Kim, M., I. Lee, and Y. Jung. 2017. "International project risk management for nuclear power plant (NPP) construction: Featuring comparative analysis with fossil and gas power plants." *Sustainability (Switzerland)* 9 (3): 1–22. https://doi.org/10.3390/su9030469.

Kucukali, S. 2011. "Risk assessment of river-type hydropower plants using fuzzy logic approach." *Energy Policy* 39 (10): 6683–6688. https://doi.org/10.1016/j.enpol.2011.06.067.

Kucukali, S. 2016. "Risk scorecard concept in wind energy projects: An integrated approach." *Renewable Sustainable Energy Rev.* 56: 975–987. https://doi.org/10.1016/j.rser.2015.12.017.

Li, Y., and X. Wang. 2016. "Risk assessment for public-private partnership projects: Using a fuzzy analytic hierarchical process method and expert opinion in China." *J. Risk Res.* 21 (8): 952–973. https://doi.org/10.1080/13669877.2016.1264451.

Liu, J., Q. Xie, B. Xia, and A. J. Bridge. 2017. "Impact of design risk on the performance of design-build projects." *J. Constr. Eng. Manage.* 43 (6): 04017010. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001299.

Ministry of Finance, Malaysia. 2016. "Study on gas-fired combined cycle power plant project in Malaysia." Accessed December 12, 2017. http://www.meti.go.jp/meti_lib/report/2016fy/000716.pdf.

Mokhtari, K., J. Ren, C. Roberts, and J. Wang. 2012. "Decision support framework for risk management on sea ports and terminals using fuzzy set theory and evidential reasoning approach." *Expert Syst. Appl.* 39 (5): 5087–5103. https://doi.org/10.1016/j.eswa.2011.11.030.

Nasirzadeh, F., M. Khanzadi, and M. Rezaie. 2014. "Dynamic modeling of the quantitative risk allocation in construction projects." *Int. J. Project Manage.* 32 (3): 442–451. https://doi.org/10.1016/j.ijproman.2013.06.002.

Novak, V. 2012. "Reasoning about mathematical fuzzy logic and its future." *Fuzzy Sets Syst.* 192 (1): 25–44. https://doi.org/10.1016/j.fss.2010.09.019.

Pall, G. K., A. J. Bridge, M. Skitmore, and J. Gray. 2016. "A comprehensive review of delays in power transmission projects." *IET Gener. Transm. Distrib.* 10 (14): 3393–3404. https://doi.org/10.1049/iet-gtd.2016.0376.

Rebeiz, K. S. 2012. "Public-private partnership risk factors in emerging countries: BOOT illustrative case study." *J. Manage. Eng* 28 (4): 421–428. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000079.

Schiffer, H.-W. 2016. "World energy resources." Accessed October 5, 2017. https://www.worldenergy.org/wp-content/uploads/2016/10/World-Energy-Resources-Full-report-2016. https://doi.org/10.03.pdf.

Shafiee, M. 2015. "A fuzzy analytic network process model to mitigate the risks associated with offshore wind farms." *Expert Syst. Appl.* 42 (4): 2143–2152. https://doi.org/10.1016/j.eswa.2014.10.019.

Singer, L. E., and D. Peterson. 2017. *International energy outlook 2017*. Washington, DC: US Energy Information Administration.

Sovacool, B. K., D. Nugent, and A. Gilbert. 2014. "Construction cost overruns and electricity infrastructure: An unavoidable risk?" *Electr. J.* 27 (4): 112–120. https://doi.org/10.1016/j.tej.2014.03.015.

Sudirman, W. B., and S. Hardjomuljadi. 2012. "Project risk management in hydropower plant projects: A case study from the state-owned electricity company of Indonesia." *J. Infrastruct. Dev.* 3 (2): 171–186. https://doi.org/10.1177/097493061100300205.

Taroun, A. 2014. "Towards a better modelling and assessment of construction risk: Insights from a literature review." *Int. J. Project Manage.* 32 (1): 101–115. https://doi.org/10.1016/j.ijproman.2013.03.004.

Tavakkoli-Moghaddam, R., S. M. Mousavi, and H. Hashemi. 2011. "A fuzzy comprehensive approach for risk identification and prioritization simultaneously in EPC projects." In *Risk management in environment, production and economy*, edited by M. Savino. London: INTECH.

Velasquez, M., and P. T. Hester. 2013. "An analysis of multi-criteria decision making methods." *Int. J. Oper. Res.* 10 (2): 56–66.

Wang, S. Q., and L. K. Tiong. 2000. "Case study of government initiatives for PRC's BOT power plant project." *Int. J. Project Manage.* 18 (1): 69–78. https://doi.org/10.1016/S0263-7863(98)00072-6.

Xia, N., X. Wang, Y. Wang, Q. Yang, and X. Liu. 2017. "Lifecycle cost risk analysis for infrastructure projects with modified Bayesian networks." *J. Eng. Des. Technol.* 15 (1): 79–103. https://doi.org/10.1108/JEDT-05-2015-0033.

Xu, Y., J. F. Y. Yeung, A. P. C. Chan, D. W. M. Chan, S. Q. Wang, and Y. Ke. 2010. "Developing a risk assessment model for PPP projects in China: A fuzzy synthetic evaluation approach." *Autom. Constr.* 19 (7): 929–943. https://doi.org/10.1016/j.autcon.2010.06.006.

Yoo, W. S., J. Yang, S. Kang, and S. Lee. 2017. "Development of a computerized risk management system for international NPP EPC projects." *KSCE J. Civ. Eng.* 21 (1): 1–16. https://doi.org/10.1007/s12205-016-0784-y.

Zaili, Y., S. Bonsall, and W. Jin. 2008. "Fuzzy rule-based Bayesian reasoning approach for prioritization of failures in FMEA." *Reliab. IEEE Trans.* 57 (3): 517–528. https://doi.org/10.1109/TR.2008.928208.

Zegordi, S. H., E. Rezaee Nik, and A. Nazari. 2012. "Power plant project risk assessment using a fuzzy-ANP and fuzzy-TOPSIS method." *Int. J. Eng. Trans. B: Appl.* 25 (2): 107–120. https://doi.org/10.5829/idosi.ije.2012.25.02b.04.

Zhao, H., and N. Li. 2015. "Risk evaluation of a UHV power transmission construction project based on a cloud model and FCE method for sustainability." *Sustainability* 7 (3): 2885–2914. https://doi.org/10.3390/su7032885.