SEMARAK ILMU PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Systematic Review of Risks in Energy Performance Contracting (EPC) Projects

Zamri Zakaria[1], Md Nazri Othman[1,*], Hidayat Zainuddin[1], Mohd Jahidi Rosdi[2], Alaa Razzaq Khallawi[3]

[1] Fakulti Teknologi dan Kejuruteraan Elektrik, Universiti Teknikal Malaysia Melaka, Jalan Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2] Jabatan Kejuruteraan Elektrik, Politeknik Port Dickson, Km 14, Jalan Pantai, 71050 Si Rusa, Negeri Sembilan, Malaysia
[3] General Company of Electricity, Transmission, Ministry of Electricity, Republic of Iraq

ARTICLE INFO

Article history:
Received 23 October 2023
Received in revised form 4 March 2024
Accepted 15 June 2024
Available online 15 July 2024

Keywords:
Energy performance contracting; risks in EPC projects; risk factors and categories

ABSTRACT

In recent years, the market trends and acceptance of Energy Performance Contracting (EPC) have caught the attention of international specialists, especially in energy management fields. EPC projects are widely acknowledged as among the most efficient global strategies for improving Energy Efficiency (EE). However, EPC projects are plagued by numerous uncertainties, which increase project risk. The impact of risk factors and categories on EPC projects can influence the effectiveness and success of implementation in EPC projects. This paper applied the pre-recording systematic reviews and meta-analysis (PRISMA) approach to determine the primary data based on a few keywords, such as "risk or uncertainty and Energy Performance Contracting or Energy Performance Contracting project". Based on advanced searching on SCOPUS and Web of Science (WOS), we found 32 selected articles (n=32). Expert scholars decided to develop three themes, which are (1) risk categories in EPC projects, (2) risk factors and categories in EPC projects, as well as (3) risk assessment methods in EPC projects. Here, the results summarise that the 19 risk factors were obtained and classified into six categories. In addition, risk assessment methods in EPC projects have been summarised. Consequently, the research findings can benefit academics and industrial practitioners in EPC projects.

1. Introduction

The market trends and acceptance of Energy Performance Contracting (EPC) have caught the attention of international specialists, especially in energy management fields, in recent years [1-3]. Energy Service Companies (ESCO) provide EPC, a service agreement, to Energy Users (EU) in order to improve Energy Efficiency (EE) [4-6]. EPC projects are widely acknowledged as among the most efficient global strategies for improving EE [7-9]. For example, [10] examines the guarantee-saving scheme among the key EPC project schemes and addresses challenges preventing its widespread use. In addition, [11] discusses how an energy-intensive manufacturer picks the best energy-saving mode

* *Corresponding author.*
E-mail address: nazri@utem.edu.my

https://doi.org/10.37934/araset.48.2.235250

with regard to non-coordination as well as coordination scenarios when faced with shared savings and self-saving possibilities.

Moreover, [12] demonstrates that the key strategies for encouraging the growth of EPC are legal protection, governmental direction, and financial incentives. However, ensuring the success of the EPC project is not a simple task to undertake. Moreover, EPC projects are plagued by numerous uncertainties, which increase project risk. The various risk factors and categories may impact the EPC projects' overall energy-saving performance and attract research interest. Many research was done to ensure the success of EPC projects.

In EPC research, there are five primary study areas that include the EPC projects' implementations, mechanisms with regard to efficient EPC projects, stakeholder behaviours as well as decisions concerning EPC projects, EPC projects' ESCO, as well as EPC projects' risk management [13]. Implementations of EPC projects refer to the EPC projects' effective implementation in various industries and nations. For example, ten key Critical Success Factors (CSFs) determining the EPC implementations in China were discovered by [14] relying on the results of a questionnaire survey as well as interviews. Effective EPC projects' mechanisms refer to the EPC project performance evaluation, EPC business models, and contract management of EPC projects. For example, [7] explored the EPC model in developed countries, for instance, United States and Europe, where the Guaranteed Savings Model is broadly utilized. Conversely, the Shared Savings Model refers to the most widely used EPC model in developing countries like China. Stakeholder behaviours and decisions with regard to EPC projects ESCO and EU were identified as the two major stakeholders regarding EPC projects. Note that their decisions and actions have a big impact on how well energy-saving measures work overall. For example, [15] utilizes the Shapley Value Method to determine the initial allocation for the energy-saving benefit of the EPC project's assured savings. ESCO in EPC projects refers to ESCO being directly involved in the majority of the management as well as operation with regard to EPC projects. The ESCO performance is crucial for assessing the EPC projects' real performance. For example, [16] promotes ESCO's innovative service business models through public procurement.

This research identified risks concerning EPC projects. Therefore, the research question examines risk factors, categories, and assessment methods in EPC projects. Risk can be defined as exposure to the consequences and impact of uncertainty [17-19]. This includes the potential for economic or financial loss, regulatory changes, delay, or failure to reach planned goals due to future uncertainty. There are still gaps in the studies on how to effectively manage the risks of EPC projects despite the risks of these projects having received sustained attention over the previous five years [1, 20, 21]. Therefore, further research should be conducted to develop better perspectives as well as methods with regard to risk assessment (identify and analyze risks) and EPC projects' risk management, for example, evaluating the risks derived from a dynamic system viewpoint.

2. Methodology

2.1 Identification

The process of choosing suitable papers for this report was categorized into three primary parts within the systematic review. Other than that, the initial stage involves keyword identification as well as the search for related terms through the utilization of resources, for example, encyclopaedias, dictionaries, thesauri, as well as prior research. Subsequently, after the determination of pertinent keywords, search strings were generated for the Scopus as well as Web of Science (WOS) databases (see Table 1). During the initial stage of the systematic review procedure, 212 papers were obtained from the selected databases successfully.

Table 1
The search strings

Scopus	TITLE-ABS-KEY ((risk* OR uncertaint*) AND (“Energy Performance Contract*” OR “Energy Performance Contract* project*”)) AND (LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2023)) AND (LIMIT-TO (SRCTYPE , “j”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (DOCTYPE , “ar”)) AND (LIMIT-TO (SUBJAREA , “ENER”) OR LIMIT-TO (SUBJAREA , “ENGI”) OR LIMIT-TO (SUBJAREA , “ENVI”))
WOS	(risk* OR uncertaint*) AND (“Energy Performance Contract*” OR “Energy Performance Contract* project*”) (Topic) and 2023 or 2022 or 2021 or 2020 or 2019 (Publication Years) and Article (Document Types) and English (Languages) and Engineering or Energy Fuels or Environmental Sciences Ecology (Research Areas)

2.2 Screening

In the preliminary screening stage, it is advisable to exclude duplicate articles from consideration. In accordance with the exclusion as well as inclusion criteria established by the researchers, a total of 149 papers were deemed ineligible and excluded during the initial phase of the study. Subsequently, 25 articles underwent evaluation during the second phase. The first criterion for selecting literature as a valuable source of knowledge is its status as a research article. Furthermore, the present study does not include publications such as meta-analyses, reviews, systematic reviews, meta-synthesis, book series, conference proceedings, chapters, as well as books. Furthermore, the scope of the review was restricted to studies conducted exclusively in English. The schedule was determined for a duration of five years (2019–2023), a fact that should be duly noted. A total of 32 publications were removed, given particular criteria.

2.3 Eligibility

In the third phase, known as the eligibility assessment, a comprehensive compilation of 33 articles was completed. At this step, a comprehensive evaluation was conducted to assess the titles and main content of all publications. The purpose of this review was to establish that the inclusion criteria were fulfilled. Other than that, the articles were made sure to possess significance to the current study and its research objectives. Consequently, one publication was excluded from consideration due to its lack of adherence to the criteria of being out of the field. A total of 32 articles are currently accessible regarding examination, as indicated in Table 2.

Table 2
The selection criterion uses searching method

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2019 – 2023	< 2019
Literature type	Journal (article)	Review, book, conference
Publication stage	Final	In press
Subject area	Energy, engineering and environmental science	Besides energy, engineering and environmental science

2.4 Data Abstraction and Analysis

The research employed an integrative analysis to assess various research designs (quantitative, qualitative, as well as mixed methods) and synthesize their findings. The primary objective identified significant topics as well as subtopics. Consequently, data collection served as the first step in theme development, as outlined in Figure 1, where the authors thoroughly examined 32 publications for pertinent assertions and material related to the study's focus. Subsequently, the authors evaluated significant studies on risk in EPC projects, examining the methodologies employed and the resulting research outcomes. Collaborating with co-authors, the authors then developed themes relying on the evidence in the study's context. Moreover, throughout the data analysis process, a log was maintained to record analyses, perspectives, queries, and other relevant thoughts for data interpretation. Subsequently, the authors make a comparison to the findings to identify any inconsistencies in the theme design process, engaging in discussions to resolve any conceptual disagreements. The produced themes were refined for consistency. To establish the findings' validity, two experts conducted an analysis selection, assessing the clarity, significance, as well as relevance of every subtheme within the field.

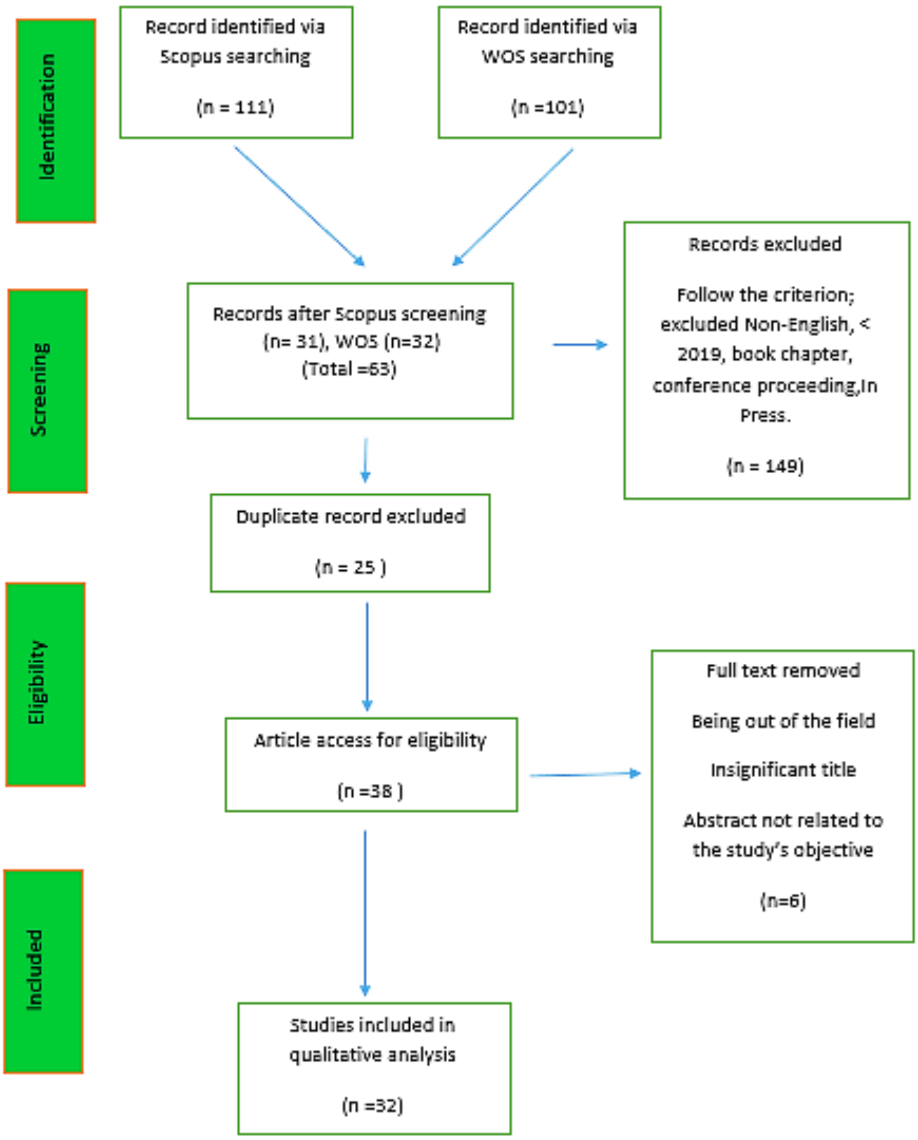

Fig. 1. The proposed searching study's flow diagram

3. Results

Here, 32 articles were extracted as well as examined utilizing the search method. Note that all articles were categorized given the three primary themes, which are risk categories in EPC projects, risk factors and categories in EPC projects, as well as risk assessment methods in EPC projects.

3.1 Risk Categories in EPC Projects

From the 32 articles read, six main categories of risks are commonly studied in EPC projects. Eight articles were read out of 32 articles discussed the entire category of risks that occur in EPC projects. For example, [22] investigated the classification and characteristics of energy performance contracting project risks. In addition, four risk categories are identified in EPC projects in China, including policy risks, market and financial risks, technology risks, as well as construction and environmental risks [23].

Figure 2 displays the six risk categories that were found as well as the number of articles that mention them. The category of risk most frequently mentioned is the "Financial and Investment" and, subsequently, the "Measurement and Verification" and "Contract" risk categories, indicating that these three categories are the most crucial regarding potential risks to the effective execution of EPC projects. The "Technological" risk category resembles the least referenced, whereas the "Behavioural and Operational" and "Regulatory and Policy" risk categories follow with regard to a number of citations and are cited in a reasonably rational manner in the literature.

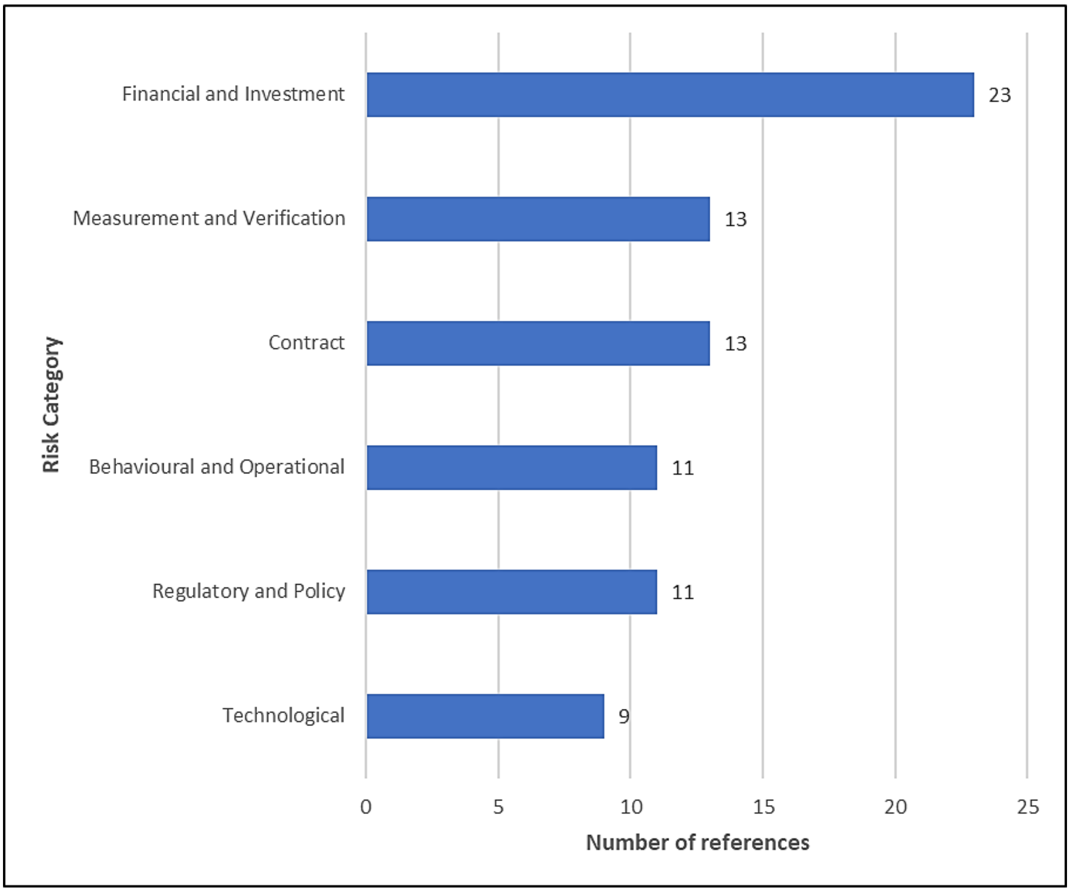

Fig. 2. Risk categories in EPC projects

3.2 Risk Factor and Categories in EPC Projects

Figure 3 shows the risk factors obtained from reading the 32 articles, which have been classified into six categories. Some articles contain more than one category and risk factor. For example, [21] have identified 21 risk factors in all, classified into five categories, which are client risks, technical risks, market and financial risks, operational and managerial risks, as well as external environmental risks.

Financial limitations are one of the major problems for EE projects. Thus, outsourcing through EPC offers a way to overcome this obstacle [24]. However, the financial and investment risk category usually occurs for ESCO and financial institutions in Shared-Saving [7, 25, 26]. The following risk factors are categorized under the financial and investment risk categories in this study: lack of finances, insufficient investment in the market, lack of skills and expertise to reduce financial or investment risks, and financing difficulties. Lack of finance is the highest risk factor because it involves a very high cost to implement these EPC projects [27-29]. In addition, high costs in the EPC project will also cause financing difficulties [30]. A lack of confidence among financiers as well as investors in the financial viability with regard to EE measures is associated with insufficient investments [31-33]. Reduced perceived financial and investment risks, as well as associated uncertainties, are necessary for EPC projects, and this requires skills and expertise in resolving these issues [34, 35].

In the Measurement and Verification (M&V) risk category, modelling error is the highest risk factor. Modelling errors could render the model useless for predicting baseline energy after retrofitting, giving rise to disagreements over the amount of energy saved [36, 37]. Poor data quality will increase uncertainty in the energy-saving calculation [38]. In addition, improper M&V design risk factor significantly affects energy consumption in EPC projects [39]. Under the contract risk category, a suitable distribution to ESCO and EU interests is required due to the numerous unpredictability abilities that affect the contract’s parameters [40]. Additionally, one of the crucial risk factors in contract risk in EPC projects is contract duration [41]. Depending on the kind of EPC projects being carried out, the EPC contract duration ranges between 5 and 7 years [24, 42].

In the category of behavioural and operational risk, inappropriate or poor maintenance carries the most risk. Consequences of poor maintenance may result in lower actual energy savings [43]. In addition, occupant behaviour is a significant factor in the uncertainties associated with building energy performance that hinder EPC projects [44]. Additionally, some weaknesses happen to ESCOs, namely a lack of qualified professionals and long duration of service in EPC projects [45].

In the regulatory and policy risk category, weak legislation is the highest risk factor. The government must acknowledge EPC as one of the most important legislative measures in order to encourage the EU, ESCO, and other stakeholders to actively participate in EPC projects [46]. In addition, insufficient effectiveness of incentive policies and lack of standardizations is a significant problem between government agencies, ESCO, and building owners [15, 47].

The technical aspects with regard to the installation equipment, as well as the worker’s abilities, are referred to as the technological risk category. Lack of competence between ESCO and energy user workers is the highest risk factor, referring to poor technical skills and inexperienced technical workers [48, 49]. Poor equipment performance risk factors yields in a reduction in actual energy-saving [50]. In contrast, the unavailable technology risk factor refers to EE technology for the EPC projects unavailable in the market [51].

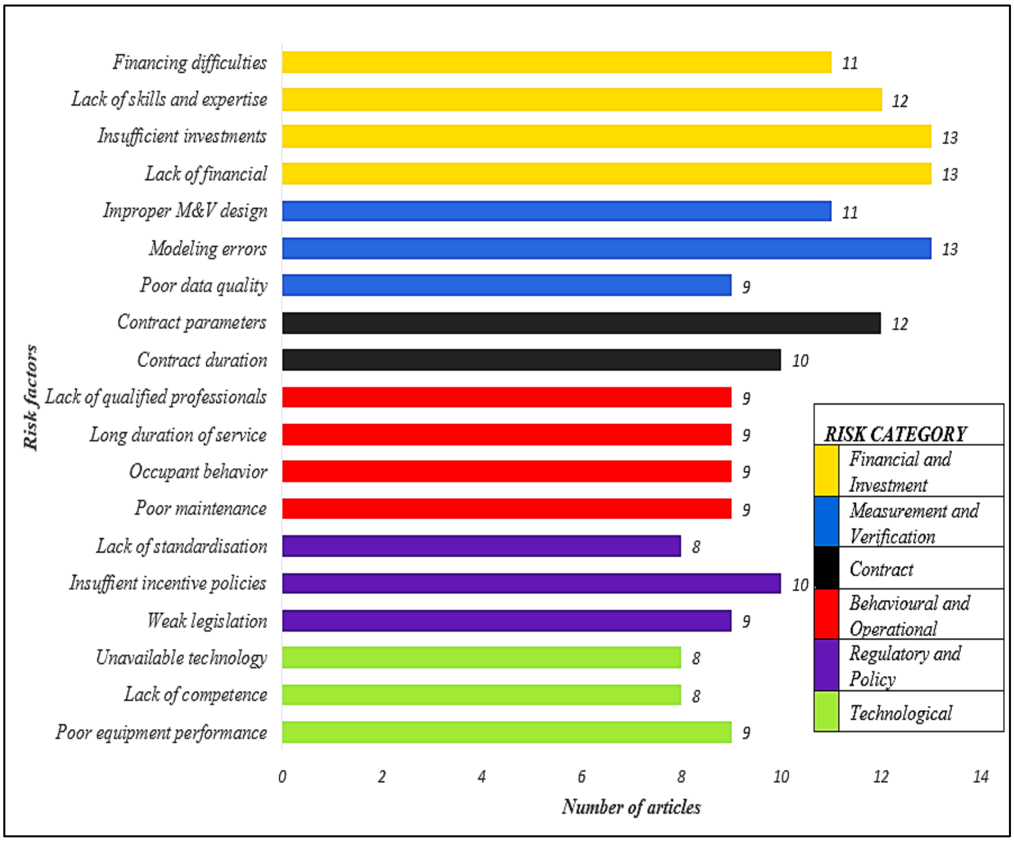

Fig. 3. Risk factors and categories in EPC projects

3.3 Risk assessment methods and application examples in EPC projects

Risk assessment methods and application examples are crucial in EPC, a strategic approach to improve EE in public and private sector facilities. EPC projects involve contracting with ESCOs to design, implement, and finance improvements, involving significant financial investments. Effective risk assessment helps stakeholders make informed decisions, ensure project success, and minimize adverse outcomes.

The fields of EPC use various risk assessment methods and applications, including qualitative and quantitative analyses, modelling techniques, and scenario planning, to guide stakeholders in EPC projects. These methods and applications help identify vulnerabilities, develop mitigation strategies, and enhance project implementation, contributing to a sustainable and energy-efficient future.

4. Discussions and Conclusions

Over the last few years, there has been a considerable increment in the number of studies on risks in EPC projects across a wide range of academic fields and industrial sectors. This article aims to synthesize and evaluate all previous research, resolve any discrepancies found in the literature, and suggest future research objectives for the capacity field. Discussions and conclusions of the key findings from the systematic literature review are provided in this section.

A study of 32 articles on risks in EPC projects identified six main risk categories: Financial and Investment, M&V, Contract, Technological, Behavioural and Operational, and Regulatory and Policy risks. Financial and Investment risks involve financing, estimating energy savings, as well as ensuring a return on investment. Measurement and Verification risks involve accurate energy savings measurement, while Contract risks involve potential disputes and ambiguities in contractual terms.

Technological, Behavioural, Operational as well as Regulatory and Policy risks involve challenges in energy-saving technologies, building occupant behavior, and regulatory changes. A holistic approach to risk management is crucial for the long-term success and growth of EPC projects.

The study identifies various risk factors in EE projects, categorized into six groups: client risks, technical risks, market and financial risks, operational and managerial risks, as well as external environmental risks. Financial limitations are a major issue for EPC projects, with lack of finances, insufficient market investment, and lack of skills and expertise being the main risk factors. In the M&V risk category, modelling error is the highest risk factor, as it can lead to disagreements over energy savings. Contract risk is crucial due to unpredictable abilities and contract duration, while behavioural and operational risk includes inappropriate maintenance and occupant behavior. In the regulatory and policy risk category, weak legislation and insufficient incentive policies are significant issues. Technological risk involves poor technical skills and inexperienced workers, reducing energy-saving. Finally, unavailable technology risk refers to EE technology for EPC projects unavailable in the market.

The information in Table 3 highlights various risk assessment methods and application examples employed in the context of EPC projects. These methods and application are instrumental in understanding, quantifying, and managing the multifaceted risks associated with EPC projects. The discussed methodologies span strategic game-theoretic models elucidating the interplay between manufacturers and ESCOs, dynamic risk allocation models for EPC projects, socio-demographic analyses influencing Implicit Discount Rates (IDRs), and multi-level risk index evaluation systems for building renovations. Furthermore, optimization frameworks such as Geometric Brownian Motion-Response Surface Method and Monte-Carlo simulations enhance decision-making in EPC contract parameters and residential retrofit projects. The incorporation of Uncertainty and Sensitivity Analysis in EPCs for EU building decarbonization and automated methods for baseline model selection showcase a commitment to reducing investment risks. Other models, including Real Option Analysis, Shapley value allocation, and fuzzy comprehensive evaluation, contribute to efficient stakeholder allocation in guaranteed savings EPC projects. The consideration of novel financing models, such as the network joint guarantee and carbon emission option, and parabolic fuzzy numbers for carbon emissions trading prices, reflects the diverse strategies employed in risk management.

In summary, these methods and applications are essential tools for understanding, assessing, and managing risks in EPC projects. They help stakeholders make informed decisions, optimize project parameters, and ensure success in a dynamic environment. As EPC projects continue to evolve, these tools are essential in navigating the challenges and uncertainties of the EE landscape.

Table 3
Summary of risk assessment methods and application examples in EPC projects

Authors	Title	Year	Source title	Risk assessment methods	Application examples
Liu *et al.,* [46]	Research on Energy Performance Contracting with Shared Savings Under Stochastic Market Demand	2023	Computers and Industrial Engineering	The game-theoretic model explains the strategic interaction that exists between manufacturer capacity decisions as well as ESCO investment in digitization and intellectualization, highlighting the effect of stochastic market demand on stakeholders and energy consumption.	Strategic decisions on capacity investment and energy savings under demand uncertainty in an ESCO-manufacturer supply chain.

Table 3. Continued
Summary of risk assessment methods and application examples in EPC projects

Authors	Title	Year	Source title	Risk assessment methods	Application examples
Wan *et al.,* [51]	Risk Allocation for EPC From the Perspective of Incomplete Contract: A Study of China's Commercial Buildings	2023	International Journal of Climate Change Strategies and Management	Three-stage EPC risk allocation model, which supports dynamic risk allocation for EPC projects.	Managing risks associated with energy conservation efforts in commercial buildings.
Schleich *et al.,* [44]	Factors Underlying the Implicit Discount Rate Tangible	2023	Energy Policy	Examines the relationship that exists between key factors underlying Implicit Discount Rates (IDR) as well as socio-demographic characteristics using household surveys in eight EU countries.	Socio-demographic characteristics such as age, income, education, and access to capital influence implicit discount rates (IDRs) related to household energy efficiency technology adoption.
Cao *et al.,* [22]	Application of energy performance contracting in building energy-saving	2022	International Journal of Environmental Technology and Management	Risk index evaluation system that is multi-level and based on the project's risk system.	EPC for building renovations, evaluated using a grey systems risk model.
Feng et al., [40]	An Energy Performance Contracting Parameter Optimization Method Based on the Response Surface Method: A Case Study of a China's Metro	2022	Energy	Framework utilizing Geometric Brownian Motion (GBM) as well as the Response Surface Method (RSM) in optimizing the EPC contract parameters.	Optimization of EPC contract parameters for an actual metro lighting renovation using GBM-RSM under uncertainty.
Natividade *et al.,* [41]	Improving the Efficiency of Energy Consumption in Buildings: Simulation of Alternative EnPC Models	2022	Sustainability	Models enable owners to bypass budgetary constraints and use private capital to finance EE measures.	The use of EPC, implemented through ESCOs, for improving efficiency in public and private buildings.
Prabatha *et al.,* [43]	An Energy Performance Contract Optimization Approach to Meet the Competing Stakeholder Expectations under Uncertainty: A Canadian Case Study	2022	Sustainability	Monte-Carlo simulation-based non-linear multi-objective optimization approach is utilized to tackle the mentioned challenges.	Optimized EPC planning for residential retrofit projects using simulations, considering financial uncertainties and stakeholder interests.
Carpino *et al.,* [33]	Uncertainty and Sensitivity Analysis to Moderate the Risks of Epcs in Building Renovation: A Case	2022	Journal of Cleaner Production	The design methodology utilizes Uncertainty as well as Sensitivity Analysis to effectively reduce investment risk.	EPC for building decarbonization, using uncertainty/sensitivity analysis to ensure energy saving forecasts and reduce risk.

	Study on an Italian Social Housing District				

Table 3. Continued
Summary of risk assessment methods and application examples in EPC projects

Authors	Title	Year	Source title	Risk assessment methods	Application examples
Agenis-Nevers *et al.,* [36]	Measurement and Verification for Multiple Buildings: An Innovative Baseline Model Selection Framework Applied to Real Energy Performance Contracts	2021	Energy and Buildings	Automated method for selecting the most suitable baseline model, incorporating climatic variables like temperature and humidity, in addition to commonly used cooling degree days.	Automated optimization of building baseline energy models for real EPC projects using enhanced climate data and algorithms.
Afroz *et al*., [39]	An Inquiry into the Capabilities of Baseline Building Energy Modelling Approaches to Estimate Energy Savings	2021	Energy and Buildings	Novel ROM technology framework to improve energy savings quantification and estimation.	Using ROM and IPMVP to measure and verify savings for EPC building retrofit projects, overcoming data limitations to simplify adoption.
Piccinini *et al.,* [38]	A Novel Reduced Order Model (ROM) Technology Framework to Support the Estimation of the Energy Savings in Building Retrofits	2021	Energy and Buildings	Novel ROM technology framework to improve energy savings quantification and estimation.	Using ROM and IPMVP to measure and verify savings for EPC building retrofit projects, overcoming data limitations to simplify adoption.
Giretti *et al.,* [45]	A Decision Support System for Scenario Analysis in Energy Refurbishment of Residential Buildings	2021	Energies	Standardized assessment methods often rely on stationary thermal models, which can introduce significant uncertainties for economically challenging contracts.	Decision support for energy efficiency investments and contracts in residential building refurbishments.
Monsberger *et al.,* [28]	Profitability of Energy Supply Contracting and Energy Sharing Concepts in A Neighborhood Energy Community: Business Cases for Austria	2021	Energies	Explores the profitability with regard to energy contractors in various business scenarios, focusing on achieving energy cost savings for residents.	Optimized design and contracting of renewable generation and cogeneration for a multi-building neighbourhood energy community.
Papachristos *et al.,* [47]	A Modelling Framework for the Diffusion of Low Carbon Energy Performance Contracts	2020	Energy Efficiency	Hybrid bottom-up as well as system dynamics modelling framework to investigate energy performance contract diffusion and its impact on operational building energy consumption and its integration concerning policy making.	Modelling the diffusion and impacts of EPCs across the building sector to reduce energy use and CO2 emissions.

Table 3. Continued
Summary of risk assessment methods and application examples in EPC projects

Authors	Title	Year	Source title	Risk assessment methods	Application examples
Shang *et al.,* [27]	Cracking the Achilles' Heel of Energy Performance Contracting Projects: The Credit Risk Identification Method for Clients	2020	International Journal of Green Energy	The rough set theory-based credit risk identification method may address the shortcomings of current EPC projects, such as lots of information as well as unclear decision rules.	A rough set theory credit risk model for EPC projects to enable ESCOs to evaluate potential clients.
Guo *et al.,* [25]	Guarantee Optimization in Energy Performance Contracting with Real Option Analysis	2020	Journal of Cleaner Production	Real Option Analysis (ROA) is utilized to evaluate managerial flexibility and uncertainty value and a flexible guarantee-saving scheme model. Mathematical equation to calculate benefit sharing percentages, enabling off-balance accounting treatment.	An improved methodology for EPC contracting using real options and optimization to increase adoption. Modelling and structuring equitable, optimal EPC-based public-private partnership contracts for EE projects.
Martiniello *et al.,* [29]	EPC and Public-Private Partnership: How to Share Risks and Balance Benefits	2020	Energies	Mathematical equation to calculate benefit sharing percentages, enabling off-balance accounting treatment.	Modeling and structuring equitable, optimal EPC-based public-private partnership contracts for EE projects.
Shang *et al.,* [15]	How to Allocate Energy-Saving Benefit for Guaranteed Savings EPC Projects? A Case of China	2020	Energy	Shapley value method for initial energy-saving allocation, AHP for risk evaluation indicators, and fuzzy comprehensive evaluation for stakeholder risk coefficients.	Allocating energy savings benefits amongst stakeholders in guaranteed savings EPC projects
Feng *et al.,* [52]	Financing Mode of Energy Performance Contract Based on Network Joint Guarantee and Carbon Emission Option for Coastal Areas	2020	Journal of Coastal Research	Concept of network joint guarantee as well as carbon emission option, highlighting their advantages in energy performance contracts in coastal areas.	An innovative ESCO financing model for EPC projects in Chinese coastal regions that provides guarantees and carbon financing to promote adoption.
Shang *et al.,* [30]	Financing Mode of EPC Projects With Carbon Emissions Reduction Potential and Carbon Emissions Ratings	2020	Energy Policy	A parabolic fuzzy number is utilized to express the fluctuation of carbon emissions trading prices as well as the risk-neutral probability and weighted interval of European call option prices.	Financing model and risk management approach for EPC projects with a focus on carbon emissions reduction.

Table 3. Continued
Summary of risk assessment methods and application examples in EPC projects

Authors	Title	Year	Source title	Risk assessment methods	Application examples
Rivalin *et al.,* [50]	Adaptation of Fan Motor and VFD Efficiency Correlations Using Bayesian Inference	2019	Science and Technology for the Built Environment	Assess motor and VFD efficiency correlations based on load and speed using manufacturer data from a vendor.	Improving the accuracy of modelling fan systems in building energy simulations, specifically for EPC projects.
Qian *et al.,* [34]	Research On Value and Factors of The Guarantee Payment in The Energy Performance Contracting in China	2019	Energy Efficiency	Valuation formula with regard to an EPC payment guarantee, a multi-period European put option portfolio having uncertain exercise prices, and analyzes the impact of factors on its value.	Enhancing trust and decision-making in EPC projects.
Töppel *et al.,* [32]	Modelling Energy Efficiency Insurances and Energy Performance Contracts for A Quantitative Comparison of Risk Mitigation Potential	2019	Energy Economics	Compares risk mitigation potential with regard to risk transfer contracts using a comprehensive energy bill savings forecast model, considering commodity prices, weather, as well as technological EE performance.	Enhancing energy efficiency investments through risk transfer contracts.
Lugarić *et al.,* [31]	Effectiveness of Blending Alternative Procurement Models and EU Funding Mechanisms Based on Energy Efficiency Case Study Simulation	2019	Energies	Evaluate the efficiency of combining alternative procurement models with EU funding mechanisms in the EE sector, considering both associated risks and benefits.	Enhancing energy efficiency in public sector projects through Alternative Procurement Models.
Newsham [37]	Measurement And Verification of Energy Conservation Measures Using Whole-Building Electricity Data from Four Identical Office Towers	2019	Applied Energy	Examine the application and validity of regression-based models	Enhanced M&V for Energy Conservation Measures (ECMs) using whole-building data.
Berghorn and Syal [49]	Risk Model for Energy Performance Contracting in Correctional Facilities	2019	Journal of Green Building	Risk analysis as well as evaluation model that incorporates quantitative, expert-based as well as probabilistically derived information.	Optimizing EPC for correctional facilities through risk analysis.
Wu and Zhou [8]	Risk Assessment of Urban Rooftop Distributed PV in EPC Projects: An Extended HFLTS-DEMATEL Fuzzy Synthetic Evaluation Analysis	2019	Sustainable Cities and Society	Examine Critical Risk Factors (CRFs) with regard to projects, as well as propose a detailed risk assessment framework.	Enhancing risk assessment for Urban Rooftop Distributed Photovoltaic (URDPV) projects through EPC.

Table 3. Continued
Summary of risk assessment methods and application examples in EPC projects

Authors	Title	Year	Source title	Risk assessment methods	Application examples
Wang *et al.,* [21]	EPC, Risk Factors, and Policy Implications: Identification and Analysis of Risks Based on the Best-Worst Network Method	2019	Energy	Identifies risk factors in China's EPC industry, develops a generic prioritization method, and proposes policy implications for decision-makers to promote harmonious development.	Enhancing risk prioritization in EPC for Industry.
Guo, K *et al.,* [26]	Optimal Scheme in Energy Performance Contracting Under Uncertainty: A Real Option Perspective	2019	Journal of Cleaner Production	ROA to find the optimal scheme for stakeholders, considering uncertainty, managerial flexibility, and investment value.	Optimizing EPC schemes using Real Option Analysis (ROA).

Acknowledgement
This research was not funded by any grant. The authors wish to extend their utmost appreciation to the Universiti Teknikal Malaysia Melaka (UTeM) for the support of facilities provided during the research.

References
[1] Xiao, Fei, Zi-yu Chen, Xiao-kang Wang, Wen-hui Hou, and Jian-qiang Wang. "Managing minority opinions in risk evaluation by a delegation mechanism-based large-scale group decision-making with overlapping communities." *Journal of the Operational Research Society* 73, no. 10 (2022): 2338-2357. https://doi.org/10.1080/01605682.2021.1981783
[2] Wang, Wentao, and Yanhua Liu. "Global trends and development of energy services industry in China." *Chinese Journal of Population Resources and Environment* 14, no. 3 (2016): 153-158. https://doi.org/10.1080/10042857.2015.1111574
[3] Bhattacharjee, Suchismita, Somik Ghosh, and Deborah Young-Corbett. "Energy service performance contracting in construction: a review of the literature." In *Proceedings of the 46th Annual International Conference of Associated Schools of Construction*. 2010.
[4] Deng, Qianli, Xianglin Jiang, Limao Zhang, and Qingbin Cui. "Making optimal investment decisions for energy service companies under uncertainty: A case study." *Energy* 88 (2015): 234-243. https://doi.org/10.1016/j.energy.2015.05.004
[5] Carbonara, Nunzia, and Roberta Pellegrino. "Public-private partnerships for energy efficiency projects: A win-win model to choose the energy performance contracting structure." *Journal of Cleaner Production* 170 (2018): 1064-1075. https://doi.org/10.1016/j.jclepro.2017.09.151
[6] Xu, Pengpeng, Edwin HW Chan, and Patrick TI Lam. "A conceptual framework for delivering sustainable building energy efficiency retrofit using the energy performance contracting (EPC) in China." *Journal of Green Building* 8, no. 1 (2013): 177-190. https://doi.org/10.3992/jgb.8.1.177
[7] Liu, Huimin, Mengyue Hu, and Xinyue Zhang. "Energy costs hosting model: The most suitable business model in the developing stage of energy performance contracting." *Journal of Cleaner Production* 172 (2018): 2553-2566. https://doi.org/10.1016/j.jclepro.2017.11.155
[8] Wu, Yunna, and Jianli Zhou. "Risk assessment of urban rooftop distributed PV in energy performance contracting (EPC) projects: An extended HFLTS-DEMATEL fuzzy synthetic evaluation analysis." *Sustainable Cities and Society* 47 (2019): 101524. https://doi.org/10.1016/j.scs.2019.101524
[9] Wu, Yunna, Jianli Zhou, Yong Hu, Lingwenying Li, and Xiaokun Sun. "A TODIM-based investment decision framework for commercial distributed PV projects under the energy performance contracting (EPC) business model: A case in East-Central China." *Energies* 11, no. 5 (2018): 1210. https://doi.org/10.3390/en11051210
[10] Guo, Kai, and Limao Zhang. "Guarantee optimization in energy performance contracting with real option analysis." *Journal of Cleaner Production* 258 (2020): 120908. https://doi.org/10.1016/j.jclepro.2020.120908

[11] Ouyang, Jianjun, and Peng Ju. "The choice of energy saving modes for an energy-intensive manufacturer under non-coordination and coordination scenarios." *Energy* 126 (2017): 733-745. https://doi.org/10.1016/j.energy.2017.03.059
[12] Yuan, Xueliang, Rujian Ma, Jian Zuo, and Ruimin Mu. "Towards a sustainable society: The status and future of energy performance contracting in China." *Journal of Cleaner Production* 112 (2016): 1608-1618. https://doi.org/10.1016/j.jclepro.2015.07.057
[13] Zhang, Wenjie, and Hongping Yuan. "A bibliometric analysis of energy performance contracting research from 2008 to 2018." *Sustainability* 11, no. 13 (2019): 3548. https://doi.org/10.3390/su11133548
[14] Zhang, Mingshun, Mujie Wang, Wei Jin, and Chun Xia-Bauer. "Managing energy efficiency of buildings in China: A survey of energy performance contracting (EPC) in building sector." *Energy Policy* 114 (2018): 13-21. https://doi.org/10.1016/j.enpol.2017.11.065
[15] Shang, Tiancheng, Peihong Liu, and Junxiong Guo. "How to allocate energy-saving benefit for guaranteed savings EPC projects? A case of China." *Energy* 191 (2020): 116499. https://doi.org/10.1016/j.energy.2019.116499
[16] Peñate-Valentín, Maria Concepción, María del Carmen Sánchez-Carreira, and Ángeles Pereira. "The promotion of innovative service business models through public procurement. An analysis of energy service companies in Spain." *Sustainable Production and Consumption* 27 (2021): 1857-1868. https://doi.org/10.1016/j.spc.2021.04.028
[17] Muriana, Cinzia, and Giovanni Vizzini. "Project risk management: A deterministic quantitative technique for assessment and mitigation." *International Journal of Project Management* 35, no. 3 (2017): 320-340. https://doi.org/10.1016/j.ijproman.2017.01.010
[18] Yusof, Mohd Fahmi Mohd, and Roslina Mohammad. "Risk management framework and practices for boiler operations in Malaysia." *Progress in Energy and Environment* (2023): 26-38. https://doi.org/10.37934/progee.23.1.2638
[19] Tyas, Ratih Luhuring, Dinnia Intaningrum, Idris Eko Putro, Ahmad Riyadl, Irvan Dwi Junianto, Alfitri Meliana, Rika Andiarti, and Arif Nur Hakim. "Risk assessment of solid propellant rocket motor using a combination of HAZOP and FMEA Methods." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 110, no. 1 (2023): 63-78. https://doi.org/10.37934/arfmts.110.1.6378
[20] Wu, Yunna, Chuanbo Xu, Lingwenying Li, Yang Wang, Kaifeng Chen, and Ruhang Xu. "A risk assessment framework of PPP waste-to-energy incineration projects in China under 2-dimension linguistic environment." *Journal of Cleaner Production* 183 (2018): 602-617. https://doi.org/10.1016/j.jclepro.2018.02.077
[21] Wang, Zhenfeng, Guangyin Xu, Ruojue Lin, Heng Wang, and Jingzheng Ren. "Energy performance contracting, risk factors, and policy implications: Identification and analysis of risks based on the best-worst network method." *Energy* 170 (2019): 1-13. https://doi.org/10.1016/j.energy.2018.12.140
[22] Cao, Min, and Ling Wang. "Application of energy performance contracting in building energy saving." *International Journal of Environmental Technology and Management* 25, no. 6 (2022): 484-500. https://doi.org/10.1504/IJETM.2022.126553
[23] Wu, Yunna, and Jianli Zhou. "Risk assessment of urban rooftop distributed PV in energy performance contracting (EPC) projects: An extended HFLTS-DEMATEL fuzzy synthetic evaluation analysis." *Sustainable Cities and Society* 47 (2019): 101524. https://doi.org/10.1016/j.scs.2019.101524
[24] Imran, Muhammad Syukri, Noor Muhammad Abd Rahman, and Roslan Mohamed. "Energy performance contracting initiative in Malaysian public hospitals." *International Journal of Integrated Engineering* 12, no. 9 (2020): 234-245. https://doi.org/10.30880/ijie.2020.12.09.028
[25] Guo, Kai, and Limao Zhang. "Guarantee optimization in energy performance contracting with real option analysis." *Journal of Cleaner Production* 258 (2020): 120908. https://doi.org/10.1016/j.jclepro.2020.120908
[26] Guo, Kai, Limao Zhang, and Tao Wang. "Optimal scheme in energy performance contracting under uncertainty: A real option perspective." *Journal of cleaner production* 231 (2019): 240-253. https://doi.org/10.1016/j.jclepro.2019.05.218
[27] Shang, Tiancheng, Xiaotong Sun, Peihong Liu, and Junqing Gao. "Cracking the Achilles' heel of energy performance contracting projects: the credit risk identification method for clients." *International journal of green energy* 17, no. 3 (2020): 196-207. https://doi.org/10.1080/15435075.2020.1712213
[28] Monsberger, Carolin, Bernadette Fina, and Hans Auer. "Profitability of energy supply contracting and energy sharing concepts in a neighborhood energy community: business cases for Austria." *Energies* 14, no. 4 (2021): 921. https://doi.org/10.3390/en14040921
[29] Martiniello, Laura, Donato Morea, Francesco Paolone, and Riccardo Tiscini. "Energy performance contracting and public-private partnership: How to share risks and balance benefits." *Energies* 13, no. 14 (2020): 3625. https://doi.org/10.3390/en13143625

[30] Shang, Tiancheng, Lan Yang, Peihong Liu, Kaiti Shang, and Yan Zhang. "Financing mode of energy performance contracting projects with carbon emissions reduction potential and carbon emissions ratings." *Energy Policy* 144 (2020): 111632. https://doi.org/10.1016/j.enpol.2020.111632
[31] Rogić Lugarić, Tereza, Domagoj Dodig, and Jasna Bogovac. "Effectiveness of blending alternative procurement models and EU funding mechanisms based on energy efficiency case study simulation." *Energies* 12, no. 9 (2019): 1612. https://doi.org/10.3390/en12091612
[32] Töppel, Jannick, and Timm Tränkler. "Modeling energy efficiency insurances and energy performance contracts for a quantitative comparison of risk mitigation potential." *Energy Economics* 80 (2019): 842-859. https://doi.org/10.1016/j.eneco.2019.01.033
[33] Carpino, C., R. Bruno, V. Carpino, and N. Arcuri. "Uncertainty and sensitivity analysis to moderate the risks of energy performance contracts in building renovation: A case study on an Italian social housing district." *Journal of Cleaner Production* 379 (2022): 134637. https://doi.org/10.1016/j.jclepro.2022.134637
[34] Qian, Dong, Guoqi Zhu, and Ju'E. Guo. "Research on value and factors of the guarantee payment in the energy performance contracting in China." *Energy Efficiency* 12 (2019): 1547-1575. https://doi.org/10.1007/s12053-019-09776-0
[35] Gombošová, Veronika, Michal Krajčík, and Ondřej Šikula. "Feasibility of using energy performance contracting for the retrofit of apartment buildings in Slovakia." *Slovak Journal of Civil Engineering* 30, no. 3 (2022): 33-42. https://doi.org/10.2478/sjce-2022-0019
[36] Agenis-Nevers, Marc, Yuqi Wang, Muriel Dugachard, Raphael Salvazet, Gwenaelle Becker, and Damien Chenu. "Measurement and verification for multiple buildings: An innovative baseline model selection framework applied to real energy performance contracts." *Energy and Buildings* 249 (2021): 111183. https://doi.org/10.1016/j.enbuild.2021.111183
[37] Newsham, Guy R. "Measurement and verification of energy conservation measures using whole-building electricity data from four identical office towers." *Applied Energy* 255 (2019): 113882. https://doi.org/10.1016/j.apenergy.2019.113882
[38] Piccinini, Alessandro, Magdalena Hajdukiewicz, and Marcus M. Keane. "A novel reduced order model technology framework to support the estimation of the energy savings in building retrofits." *Energy and Buildings* 244 (2021): 110896. https://doi.org/10.1016/j.enbuild.2021.110896
[39] Afroz, Zakia, H. Burak Gunay, William O'Brien, Guy Newsham, and Ian Wilton. "An inquiry into the capabilities of baseline building energy modelling approaches to estimate energy savings." *Energy and Buildings* 244 (2021): 111054. https://doi.org/10.1016/j.enbuild.2021.111054
[40] Feng, Zongbao, Xianguo Wu, Hongyu Chen, Yawei Qin, Limao Zhang, and Miroslaw J. Skibniewski. "An energy performance contracting parameter optimization method based on the response surface method: A case study of a metro in China." *Energy* 248 (2022): 123612. https://doi.org/10.1016/j.energy.2022.123612
[41] Natividade, Jorge, Carlos Oliveira Cruz, and Cristina Matos Silva. "Improving the efficiency of energy consumption in buildings: simulation of alternative enpc models." *Sustainability* 14, no. 7 (2022): 4228. https://doi.org/10.3390/su14074228
[42] Zhang, Wenjie, and Hongping Yuan. "Promoting energy performance contracting for achieving urban sustainability: What is the research trend?." *Energies* 12, no. 8 (2019): 1443. https://doi.org/10.3390/en12081443
[43] Prabatha, Tharindu, Kasun Hewage, and Rehan Sadiq. "An energy performance contract optimization approach to meet the competing stakeholder expectations under uncertainty: A Canadian case study." *Sustainability* 14, no. 7 (2022): 4334. https://doi.org/10.3390/su14074334
[44] Schleich, Joachim, Xavier Gassmann, Thomas Meissner, and Corinne Faure. "Making the factors underlying the implicit discount rate tangible." *Energy Policy* 177 (2023): 113563. https://doi.org/10.1016/j.enpol.2023.113563
[45] Giretti, Alberto, Alessandra Corneli, and Berardo Naticchia. "A decision support system for scenario analysis in energy refurbishment of residential buildings." *Energies* 14, no. 16 (2021): 4738. https://doi.org/10.3390/en14164738
[46] Liu, Chunhui, Wenhui Zhou, and Jiguang Chen. "Research on energy performance contracting with shared savings under stochastic market demand." *Computers & Industrial Engineering* 176 (2023): 108877. https://doi.org/10.1016/j.cie.2022.108877
[47] Papachristos, George. "A modelling framework for the diffusion of low carbon energy performance contracts." *Energy Efficiency* 13 (2020): 767-788. Papachristos, George. "A modelling framework for the diffusion of low carbon energy performance contracts." *Energy Efficiency* 13 (2020): 767-788. https://doi.org/10.1007/s12053-020-09866-4
[48] Zhang, Wenjie, and Hongping Yuan. "A bibliometric analysis of energy performance contracting research from 2008 to 2018." *Sustainability* 11, no. 13 (2019): 3548. https://doi.org/10.3390/su11133548

[49] Berghorn, George H., and Matt Syal. "Risk model for energy performance contracting in correctional facilities." *Journal of Green Building* 14, no. 2 (2019): 61-82. https://doi.org/10.3992/1943-4618.14.2.61
[50] Rivalin, Lisa, Marco Pritoni, Pascal Stabat, and Dominique Marchio. "Adaptation of fan motor and VFD efficiency correlations using Bayesian inference." *Science and Technology for the Built Environment* 25, no. 7 (2019): 836-848. https://doi.org/10.1080/23744731.2019.1571869
[51] Wan, Shiyu, Yisheng Liu, Grace Ding, Goran Runeson, and Michael Er. "Risk allocation for energy performance contract from the perspective of incomplete contract: A study of commercial buildings in China." *International Journal of Climate Change Strategies and Management* 15, no. 4 (2023): 457-478. https://doi.org/10.1108/IJCCSM-11-2021-0130
[52] Feng, Luyao, Jingjuan Guo, and Ying Li. "Financing mode of energy performance contract based on network joint guarantee and carbon emission option for coastal areas." *Journal of Coastal Research* 107, no. SI (2020): 317-322. https://doi.org/10.2112/JCR-SI107-075.1