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Promoting Energy Performance Contracting for Achieving Urban Sustainability: What is the Research Trend?

Wenjie Zhang ¹ and Hongping Yuan ^{2,*} 

¹ School of Economics and Management, Southwest Jiaotong University, 111 North 1st Section of 2nd Ring Road, Chengdu 610031, China; zwenjie2016@my.swjtu.edu.cn

² School of Management, Guangzhou University, 230 Wai Huan Xi Road of Guangzhou Higher Education Mega Center, Guangzhou 510006, China

* Correspondence: hpyuan@gzhu.edu.cn; Tel.: +86-136-1802-8376

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Abstract: The increasing demand for applying energy performance contracting (EPC) for urban energy conservation has resulted in a significant amount of publications over the past decade. This study tries to identify future research trends in the subject of EPC through analyzing 127 journal papers published from 2008 to 2018. Based on the analysis and discussion of the EPC research, several main research trends were identified. The research results reveal an increasing research interest in EPC over the period. The findings imply that case study is the major research method and descriptive analysis and statistical analysis are primarily used for data analysis. In addition, EPC research in the past decade focused on five major research topics, which are ‘implementation of EPC projects’, ‘EPC mechanism and business models’, ‘decision-making in EPC projects’, ‘Energy Service Companies (ESCOs) in EPC projects’, and ‘risk management in EPC projects’. Based on the five research topics, future research trends and directions in EPC were identified as well. The findings of this study can be informative and valuable for guiding future research in EPC, and are particularly helpful for researchers who are keen to open a new window of investigating EPC issues worldwide.

Keywords: energy; energy performance contracting; review; sustainability; research trend

1. Introduction

Energy performance contracting (EPC) has been commonly regarded as a critical and valuable energy conservation mechanism in urban development, under which an energy service company (ESCO) provides an energy-saving service to the energy user (EU) and shares the energy cost-savings with EUs together [1–4]. The EPC mechanism has been proven to be applicable and beneficial to diverse sectors typically including iron, steel, coal, chemical, buildings, electricity, and energy [5,6]. Over the last decade, with a major initiative being energy conservation, a lot of EPC-related studies have been published in scholarly journals due to the perceived benefits of effectively promoting energy efficiency [3,7–10]. While these studies contribute significantly to the knowledge of energy management, they present a challenge for scholars to grasp an overview of EPC research. It is difficult to learn and understand the research progress in EPC field because of the dramatic increase of the publications in a short period. Therefore, it is of vital importance to systematically investigate the EPC-related literature, which would be helpful in inspiring and guiding future research trends on the subject.

Literature review has long been adopted as a useful methodology for examining the development trend of research in a particular discipline. For example, Felix and Stefan [11] reviewed the terms of air cargo loading and identified the gaps between the current planning practice and research. To identify

different parameters for measuring embodied energy, Materla et al. [12] analyzed existing literature on the Kano model and provided a valuable guide to further research in service quality improvement of the healthcare industry. With a review on construction and demolition waste (CDW) management research published in eight international journals, Yuan and Shen [13] informed several research trends of CDW management worth further investigations. Based on over 180 publications, Volk et al. [14] conducted a systematic literature review of BIM, which was claimed to be effective in revealing current trends and research gaps in the area. Jin et al. [15] carried out a review-based study for evaluating the recent decade's construction waste management research and proposed a framework for guiding near-future research in the area. Obviously, the above review-based studies have provided researchers with complete understanding on the current development of research, and guided new researchers intending to launch new studies to avoid duplication of research efforts. Also, those review outcomes have presented new and noteworthy research directions. Therefore, review-based research is important to allow researchers to learn the current research progress and the potential research trends in a research subject concerned.

In the field of EPC, very few review-based studies were spotted based on a thorough literature search and scan. A recent study by Shang et al. [16] is one among such attempts. Their study, based on an analysis of EPC-related research, reviewed mainly four aspects: (1) different characteristics of EPC business models (EPCBMs), (2) EPCBM selecting methods, (3) the impact of EPCBMs on EPC project performance, and (4) critical factors affecting the EPCBM selection. It is apparent that their focus is on the EPCBMs (i.e., Shared Savings Model, Guaranteed Saving Model, and Chaffee Model in their study), instead of analyzing EPC literature in a broad sense. Therefore, no comprehensive EPC review has been conducted for understanding latest research progress and arousing future research trends.

To fill the above research gap, this study is carried out to discuss latest research and present future research trends on EPC by extensively reviewing relevant publications from 2008 to 2018. Specifically, the following questions are to be answered.

- (1) What themes or topics of EPC research had been put attentions by scholars in the past decade?
- (2) What research methods and data analysis methods were primarily adopted in EPC studies from 2008 to 2018?
- (3) What can be the potential research trend of EPC research in future?

The paper is organized as follows. In Section 2, we will brief the research on EPC; then we will introduce the research methodology, such as how to select the target documents and papers and how to classify the identified papers. In Section 4, the results will be presented with detailed analyses and discussions, including EPC publication trends in the past decade and a discussion of research methods and data analysis methods and the major EPC research topics. Section 5 will present future research trends in EPC; finally, we will conclude the paper.

2. Overview of Energy Performance Contracting

Originated from the oil crisis in 1970s, EPC was created as an innovative financing mode mainly for reducing energy consumption through recompose for costs of installing and managing energy-saving equipment [17]. EPC nowadays has been widely applied in various industries for energy conservation and received widespread attention from scholars [4,7,18,19]. In the context of construction industry for instance, EPC is perceived as a market mechanism or financing tool to encourage building owners to carry out energy retrofits [7]. Under such a mechanism, an ESCO normally provides EU with a series of energy-saving products or services, including energy auditing, EPC financing, energy-saving designing, equipment purchasing, and energy accounting [4]. Quite different from traditional mechanisms, the ESCO mainly profits from EPC projects through bearing energy-saving costs and sharing energy retrofit benefits with the EU [18].

Along with the emerging policies and standards for encouraging EPC, worldwide EPC markets have been developing rapidly over the past decade, though with different stages of market maturity. The great variation of EPC market development among different countries and regions has been evident

that USA's EPC market has experienced a rapid growth since 2000, while the whole development of EPC in European and Asian regions is much slower [10,20]. The sectors for EPC application are also quite different. In many developed countries, such as USA, Japan, Canada, UK, Finland, and Australia, EPC is mainly adopted for building energy-efficiency retrofits (see: [2,7,21–24]). However, in some developing countries, such as China, EPC is primarily applied in coal, iron and steel [4], paper-making [25], and building sectors [26]. Such a difference in EPC application can be related to the particular socioeconomic context of the countries concerned.

A major concern about applying EPC is how to promote EPC successfully in a given market. In this regard, several research efforts have been devoted to barriers of applying EPC, particularly in some emerging markets. For example, Painuly et al. [26] examined the EPC mechanisms and ESCOs' financing barriers in developing countries. Studies of Xu et al. [6,7] and Xu and Chan [27] attempted to explore major factors affecting the sustainable building energy efficiency retrofit of hotel buildings in China. Zhang et al. [10] proposed a framework for applying EPC in the real estate industry. From a qualitative perspective, Yuan et al. [28] analyzed the status and future of EPC through investigating the evolution of EPC policy system in China. Aasen et al. [29] explored the important factors affecting the EPC and the barriers to energy savings in Norway's municipal sector. Polzin et al. [23] empirically studied the EPC barriers in the retrofitting projects in German municipalities.

With the above barriers unsolved, the operation and development of EPC projects would encounter a set of risks and uncertainties, which are influential to project success [30]. Hu and Zhou [31] summarized major risks in EPC project development, including the political and legal risks, technology-related risks, management risks, financial risks, project quality risks, and client-related risks. Qian and Guo [32] pointed out that risks and uncertainties in EPC projects are largely related to energy prices, equipment utilization, unexpected events, contract risks, and so on. Based on empirical evidence, Lee et al. [33] identified the critical risks in EPC projects, such as the EU's potential payment default after installation, inaccuracy of baseline measurement, and increase in installation cost. Besides, the literature also suggested other risks that decision-makers in EPC projects should be aware of, such as low awareness and consciousness of EPC project development [34,35], technical barriers and risks [36,37], and insufficient policy supports for applying EPC [28].

EPC is a turnkey service providing clients with a general overview of energy efficiency, renewable energy, and distributed generation measures, which are always accompanied with energy savings guarantees. In EPC projects, the project energy savings fulfill all initial investment [7,17,26]. Therefore, financing has been a core element in EPC projects. Sarkar and Singh [38] discussed the critical financing factors affecting EPC energy-saving solutions in major developing countries. Li [5] evaluated the financing problems in China's EPC projects with an AHP-Fuzzy approach; particularly, the financing problems in five industries were targeted, including iron, steel, chemical, building, electricity, and energy. Li et al. [25] highlighted the importance of effective financing to EPC projects development through exploring the detailed clauses of Chinese EPC projects.

EPC provides a cooperative mechanism between ESCOs and EUs [4,21]. As an integral component of EPC, ESCO has been playing a critical role in affecting the operation and development of EPC projects [39]. Based on information in 38 countries outside of the US, Vine [1] provided a comprehensive analysis of ESCO development mainly covering the number of ESCOs, the significant sectors targeted by ESCOs, the major important barriers in ESCO industry, and the future of the ESCO industry in a particular country. Based on discussion and analysis of the current status of ESCO industries in the EU and the New Accession Countries, Bertoldi et al. [40] developed a long-term strategy to support the development of ESCOs in Europe. Based on a model analysis by using on a panel data of 94 countries from 1981 to 2007, Fang et al. [41] proved that ESCOs reduce energy use effectively. Through an analysis of the EPC market institutions in China, Kostka and Shin [42] argued that trust-based relationship between ESCO and EU is essential for successful implementation and operation of EPC projects. In the study of Deng et al. [43,44], a methodology was advocated to assist ESCOs to keep competitiveness in winning bids, which was claimed to be effective in finding the reasonable guaranteed savings value in

EPC projects. Using a game-theoretic model, Zhou et al. [4] investigated the competitiveness of two competing manufacturers with EPC mode.

3. Research Method

3.1. Selection of Target Scholarly Papers

This study adopts a rigorous approach to investigate the EPC-related literature from 2008 to 2018 published in Web of Science (WoS). The overall procedure of paper selection and filter comprises three steps, as introduced below.

Firstly, the scholarly paper selection started from scanning and retrieving papers in a prevailing academic database—WoS—which is one of the major databases for indexing academic publications. The literature search was performed by inputting the topics of “energy performance contracting” in WoS, attempting to identify related papers published in English during 2008 to 2018. The paper search resulted in 1743 papers.

Secondly, we filtered the paper based on the type of papers. After a comprehensive categorization of the 1743 papers retrieved, it was found that different types of papers were involved, such as Journal Article, Conference Article, Review, Other, Thesis Dissertation, and Book. We excluded conference papers in the search considering that conference papers did not provide as much information as journal articles do, and this practice has been commonly applied in some prior review-based studies [13,45]. The paper filter resulted in 894 journal papers.

Finally, the journal papers were further filtered for identifying the papers highly related to EPC. The filter was based on the following keywords; TITLE-ABS-KEY (“energy performance contracting” OR “energy performance contract” OR “EPC” OR “energy management contract”). The keywords search resulted in 127 journal papers, which were confirmed as the sample of the present study.

3.2. Classification of the Identified Papers

All 127 papers identified were classified to obtain further insight into understanding the research trend of the EPC subject. Through the paper classification we targeted one objective: to learn what the research and data analysis methods employed by prior literatures were. It was observed that the research methods adopted by previous studies vary a lot, mainly covering survey, case study, and theoretical/mathematical analysis, which are explained as follows.

- Survey: This is performed by using manners such as questionnaire, interviews, site visits, etc. to carry out survey with EPC industry practitioners, in order to collect their opinions toward EPC-related issues. This has been a common way for collecting data in the broad discipline of energy management (e.g., [3,7,22,46,47]).
- Case study: Case studies form a significant proportion of EPC literature, examine status quo and barriers and propose measures for promoting EPC applications based on a thorough analysis and discussion of realistic EPC cases/projects (e.g., [23,39,44,48,49]).
- Theoretical/mathematical analysis: Given that EPC involves two major stakeholders, i.e., the ESCO and the EU, their decisions can be dynamic and interrelated in EPC project development. Thus, an obvious stream of studies was conducted to examine the dynamic decision-making process, mostly based on the game theory (e.g., [4,32,50–52]). Data in such a sample were all hypothesized based on an abstract of real-world EPC project practices. Also, there is another stream of studies focusing on examining EPC issues through developing mathematical tools through approaches such as ANP, AHP, AHP-Fuzzy, and Monte Carlo (e.g., [27,53,54]). Data in these studies were largely based on survey outcomes with EPC practitioners.

In addition, the review of the sample papers indicated four kinds of data analysis methods for carrying out EPC research, covering descriptive analysis, statistical analysis, model and simulation, and cost-benefit analysis.

- ◆ Descriptive analysis was commonly used in studies aiming at identifying the problems and measures of EPC industry and project development. Data in these studies were always analyzed by calculating the mean value and standard deviation, providing strong supports to the statements or arguments (e.g., [21,55–58]).
- ◆ Statistical analysis was useful for carrying out deeper data analysis compared with the descriptive analysis. Normally methods such as factor analysis and regression analysis were adopted for performing statistical analysis (e.g., [7,17,47]).
- ◆ Modeling and simulation refer to performing data analysis through various mathematical modeling techniques and professional simulating software packages to examine EPC issues, such as the interacted decision among major EPC stakeholders (e.g., [51,54,59,60]).
- ◆ A cost-benefit analysis reveals the economic benefits and costs of EPC activities. Net Present Value (NPV) and the Black–Scholes model are common analytic tools used for such studies (e.g., [5]).

4. Results, Analysis, and Discussions

4.1. Trend of EPC Publications in the Past Decade

The number of EPC related papers published from 2008 to 2018 is shown in Figure 1. It is clear that there is a dramatic increase in annual publications, demonstrated by the number of publications of 1 (year 2008) to 21 (year 2018). A direct observation of the results is that EPC has been attracting more and more attention over the past decade.

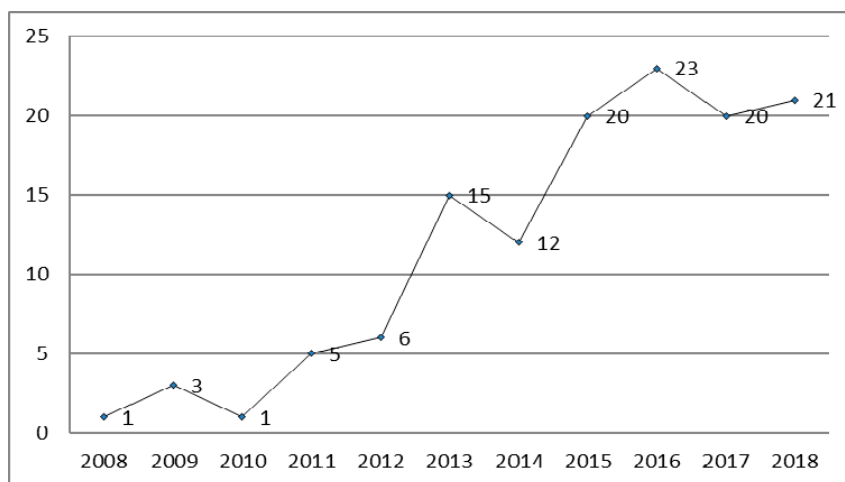


Figure 1. Yearly energy performance contracting (EPC)-related publications from 2008 to 2018.

4.2. Research Methods and Data Analysis Methods

All the 127 identified papers were classified according to the previously outlined research methods, as shown in Table 1. It is obvious that the three methods, i.e., case study, theoretical/mathematical analysis, and survey, were almost equally applied in EPC research, though case study received the highest proportion (36.22%). It is also observed that case study and survey together accounted for more than 70%. This is understandable given that EPC is closely related to industry practices, it is thus a precondition for collecting data through industry surveys and interviews, and observes before reasonable and practicable suggestions can be developed.

Table 1. Research methods in the sample papers.

Research Method	Number of Papers	%
Case study	46	36.22
Theoretical/Mathematical Analysis	43	33.86
Survey	38	29.92

The 127 papers identified were also classified according to the data analysis methods previously discussed (see Table 2). The results show that 43 papers have used modeling and simulation methods, 41 papers used descriptive analysis method, and 36 papers adopted statistical analysis method. Although assessment of EPC project benefits is regarded as critical for promoting EPC project implementation, only seven papers have attempted to deal with this issue by adopting the cost-benefit analysis method. A close examination of the data analysis methods in the sample told that, in most early studies (e.g., [1,2,26]), descriptive and statistical analysis methods were applied for data analysis because those data were all obtained through industry survey including the Delphi approach (e.g., [3,46]), questionnaires, and interviews (e.g., [36,47]). However, recently, more and more modeling and simulation methods have been applied for data analysis, such as Fuzzy Neural Network (FNN) [61], Monte Carlo simulation [43], Data Envelopment Analysis (DEA) [16], Structural Equation Model (SEM) [56], and game theory approach (e.g., [4,25,50,62]). The evolution of data analysis methods in the sample indicated that newly developed data analysis methods, such as modeling and simulation methods, have been playing an important role in EPC research.

Table 2. Data analysis methods in the sample papers.

Data Analysis Method	Number of Papers	%
Modeling and simulation	43	33.86
Descriptive analysis	41	32.28
Statistical analysis	36	28.35
Cost-benefit analysis	7	5.51

4.3. The Five Main Research Topics

The exploration and analysis of EPC research topics not only contributes to better highlight and understand the past research focus and evolution of EPC research over the concerned period, but are also important in efforts of avoiding the repeat and duplication of research. In order to achieve easy analysis and understanding of major topics involved in the identified papers, it is important and critical to classify the 127 papers into several clusters.

A three-step procedure was designed to facilitate the paper classification process. Firstly, a preliminary scan of the title, abstract, and keywords of the identified 127 papers were carried out to achieve an initial judgment of its research topic. In the process, papers belonging to same or similar research topics/themes are put into a cluster. Taking the sample [17] as an example, following this approach it was easily found that this paper can be related to the topic of “the operation of ESCO”. It should be noted that during this stage it is possible that one paper can be related to two or more topics simultaneously.

Secondly, the outcomes of topic classification were checked and confirmed by the research team. The focus of this step was on the classification of papers belonging to two or more topics. A thorough reading and evaluation would be conducted for such papers. Also, discussions among team members might be performed for reaching a consensus on the selected research topic of a paper. A basic rule we used is that when a paper involves more than one topic, it will be related to the most highly related topic. In the execution process, one author completed this task firstly. Then, the outcomes obtained were double-checked by the second author to make necessary adjustments. As a result, all identified papers were related to specific topics.

Thirdly, based on the above, both the contents of the identified papers and the research topics obtained in the second step were carefully analyzed to form some broader clusters of topics. For instance, topics of the EPC business model, evaluation of EPC projects, contract arrangement/management in EPC projects, and EPC market/mechanism were generally related to EPC business models and EPC mechanism. Consequently, they were categorized under the cluster of EPC mechanism and business models, which is the first-level topic as documented in Table 3.

Table 3. Research topics in the 127 papers.

Clusters of Research Topics	Subtopics
T1: Implementation of EPC projects	Factors affecting implementation of EPC projects, EPC practices in various sectors and regions, EPC practices in public institutions, and major barriers to promoting EPC projects, which can be related to financing, technology, and policy, for example.
T2: EPC mechanism and business models	Evaluation of EPC projects, contract arrangement/management in EPC projects, EPC market/mechanism, EPC business models.
T3: Decision-making in EPC projects	Major practitioners' behavior in EPC projects, two-party game, three-party game, and optimal decision-making in EPC projects.
T4: ESCOs in EPC projects	Diffusion of ESCOs, choice of ESCO models, and the policies and operation of ESCOs.
T5: Risk management in EPC projects	Critical risks in EPC projects, risk evaluation for EPC projects, and risk and benefit analysis of EPC projects.

Eventually, five clusters covering 17 research subtopics were mainly observed, including (1) implementations of EPC projects, (2) EPC mechanism and business models, (3) decision-making in EPC projects, (4) ESCOs in EPC projects, and (5) risk management in EPC projects. The subtopics covered by each cluster are tabulated in Table 3.

According to the number of papers annually published in the five research topics (see Table 4), it is clear that significant efforts have been devoted to studies on “implementation of EPC projects” (33.07%), “EPC mechanism and business models” (19.69%), “decision-making in EPC projects” (18.11%), “ESCOs in EPC projects” (14.96%), and “risk management in EPC projects” (14.17%). Besides, it is evident that in recent years all the five research topics tend to attract more and more research attentions.

Table 4. Number of papers on different research topics (2008–2018).

Research Topics	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total	%
T1: Implementation of EPC projects	0	2	0	3	2	7	4	6	7	7	4	42	33.07
T2: EPC mechanism and business models	1	1	1	0	3	2	2	3	7	3	2	25	19.69
T3: Decision-making in EPC projects	0	0	0	0	0	2	3	3	5	4	6	23	18.11
T4: ESCO in EPC projects	0	0	0	1	1	1	2	5	2	3	4	19	14.96
T5: Risk management in EPC projects	0	0	0	1	0	3	1	3	2	3	5	18	14.17

The topic of “implementation of EPC projects” attracted the largest proportion of research efforts. This topic concerns how to promote development of EPC project and industry, and has been related to a relatively wide range of subtopics, such as factors affecting implementation of EPC projects, EPC practices in various sectors and regions, EPC practices in public institutions, and major barriers to

promoting EPC projects (e.g., [39,47,63]). Compared with other topics, from 2011 to 2018, the number of papers published in this topic kept in a relatively higher level. This topic can be expected to continuously attract more research attention in the future because implementing EPC projects in various regions and economies should envisage the different external and internal environment over the entire lifecycle of project operations [16,24,28].

The topic of “EPC mechanism and business models” resulted in the second highest number of publications from 2008 to 2018. This topic concerns the effectiveness of EPC projects and EPC industry; particularly, subtopics of evaluation of EPC projects, contract arrangement/management in EPC projects, EPC market/mechanism, and EPC business models were involved (e.g., [46,49,52]). This topic tends to be an important focus in the future because how to effectively evaluate EPC project performance and develop EPC market and business is critical [44,50].

It is not until 2013 that the topic of “decision-making in EPC projects” began to attract research interests, demonstrated by a steady number of publications from 2013 to 2018. This can be a very important research domain continuously attracting research interests because the decisions among major EPC project stakeholders are influential in shaping project performance (e.g., [19,25,55]).

As one of the most critical stakeholders in EPC projects, ESCO has been developed as an independent research topic, and related publications have been increasing since 2014. It should be highlighted that studies belonging to this topic were closely related to those in the topic of “decision-making in EPC projects”. This overlap is understandable because both topics would involve the analysis of the critical stakeholder—ESCO. The topic shows specific interests in diffusion of ESCOs, choice of ESCO models, and the policies and operation of ESCO (e.g., [64–68]). Due to the vital importance of ESCO in affecting the overall performance of EPC projects [40,41], this topic will be attracting significant attention from global researchers.

The topic of “risk management in EPC projects” dealt with project risks with an ultimate purpose of minimizing EPC project risks and maximizing project benefits. Starting from 2013 onwards, this topic received more and more research attention due to the fact that each EPC project should take good care of major risks to prevent project loss [32,33]. It is believed that this topic would be continuously important due to uncertainties existing in EPC projects, such as fluctuations of future energy price, and the unpredictable accident and energy saving shortfall [8,30,44,53].

4.4. Future Research Trends

Along with the identification and discussion of the five research topics in the EPC subject, major research directions or trends worth future investigations were explored as well. The future research directions were mainly based on in-depth analysis of the status quo of EPC research, given the five research topics identified in current EPC publications.

Particularly, when identifying the EPC research trends, two main strategies were applied. The first strategy is that we identified future research trends based on evaluation of the annual number of papers on different research topics, because we believe this implies whether the topic receives continuous attention from global researchers, and topics attracting significant research attention can be potentially important in the future. For example, the identification of research trends of cluster “Decision-making in EPC projects” followed such a strategy. It is easily observed from Table 4 that papers related to this topic increases significantly from 2013 to 2018, with the highest number of papers in 2018. Thus we believe this can be a topic deserving more attention in the future.

The other is we predict future research trends based on the current and prior topics or themes documented by the contents. Following this strategy, we carried out an in-depth analysis of the paper contents with a special focus on the research limitations and future research proposed by the authors (if any). It should be noted that this strategy applied to all analysis of papers, even though those papers adopting the former strategy.

In line with the two strategies, we obtained the outcomes shown in Figure 2. In the following section, we will focus on discussing and explaining major future research trends and directions in each research topic.

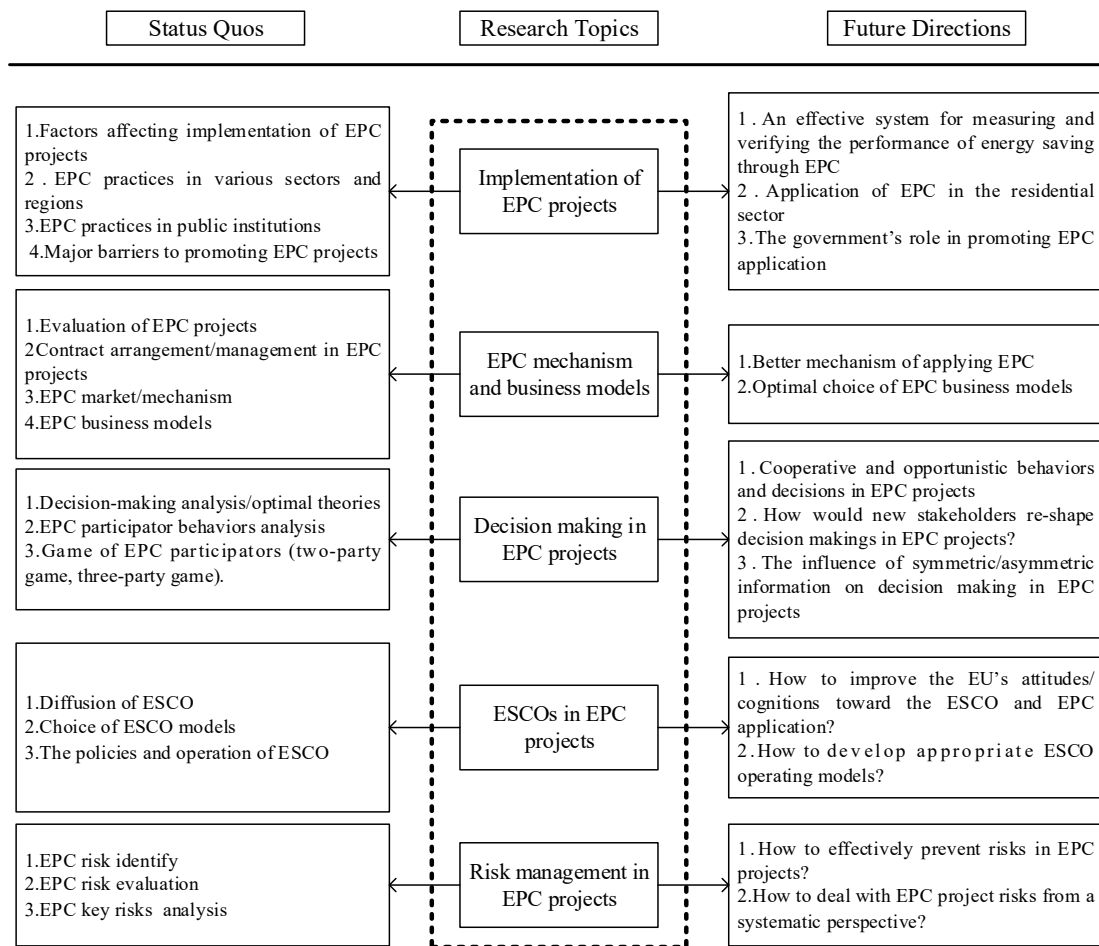


Figure 2. Future research directions/trends in the EPC subject.

4.4.1. Research Trend of “Implementation of EPC Projects”

The topic of “implementation of EPC projects” has attracted the most attention, and three major subtopics need to be further explored:

(1) An effective system for measuring and verifying the performance of energy saving through EPC. As a mechanism claimed to be effective in saving energy consumption, EPC has been implemented in a wide range of areas, encompassing building energy efficiency retrofits [7,27,69], real estate industry [10,70], public light system [30,71], and the iron and steel industry [4]. A core initiative of applying EPC in the above areas is to achieve energy savings agreed by ESCOs and EUs. However, the project's operation may last several years and be subject to external environment changes causing various uncertainties and risks. Those uncertainties and risks would bring challenges to achieving the agreed energy savings as documented by the project contract [32,54,72]. For example, Lee et al. [8] demonstrated that it is very difficult to verify whether the expected energy saving has been obtained by implementing the energy efficiency retrofits due to inaccurate measurement parameters. In addition, some prior studies [7,10,27] argued that measuring and verifying the energy-saving quality of EPC projects is critical in limiting the diffuse of EPC. In recent years, increasing studies about how to accurately measure and verify energy conservation and what are the effective and reasonable methods evaluating the energy-saving of EPC projects have been conducted (e.g., [69–72]). In this regard,

it is critical to develop a system for effectively measuring and verifying whether the EPC project has achieved expected energy savings, which has long been lacking in the literature. The development of such a system would involve indicators, procedures, and standards and methods for measuring and verifying energy savings.

(2) Application of EPC in the residential sector. Previous literatures mostly focused on applying EPC to deal with energy savings in the commerce and public institutions, such as hotel buildings [6,37], hospitals and community clinics [9,35], and the municipal sector [23,29,63,73]. However, with the development of urbanization, there is a pressing need to reduce energy consumption in the residential sector, considering that large-scale residential buildings are responsible for a significant proportion of the total energy usage [74,75]. This is particularly severe in developing countries and regions which are undergoing a rapid speed of urbanization and urban renovation [36]. Studies have proven that EPC is a useful housing energy efficiency retrofit mode based on the residential building cases from Germany, Ethiopia, and Norway [23,72,74]. In addition to the problems caused by the ‘rebound effect’ (e.g., [76–78]) in residential buildings’, an EPC energy-efficiency retrofit would also be paid more attentions by researchers in future. Thus, the adoption of EPC in the residential sector can be potentially effective in reducing energy consumption and worth more studies in the future.

(3) The government’s role in promoting EPC application. It is observed that barriers in terms of financing and government policies were frequently studied from 2008 to 2018. For example, Sarkar and Singh [38], Li [5], and Li et al. [25] attempted to address the financing bottlenecks in EPC projects. Zhang et al. [34] and Yuan et al. [28] argued that the deficiency of governmental support of policies limited the development of EPC projects. Actually, both dimensions of the barriers are highly related to a government that plays a leading role in cultivating the external environment for carrying out EPC projects, and therefore the government is critical to successful implementation of EPC projects [33,79]. In fact, recently several studies have recognized the role of government in EPC application and diffusion. For example, Li [5] argued that the government’s economic policy could deal with the financing problems of EPC effectively; Lu and Shao [50] insisted that government subsidies can promote EPC diffusion. In this regard, it is essential to investigate the effective role of the government in promoting EPC application in various sectors in future research.

4.4.2. Research Trend of “EPC Mechanism and Business Models”

Under the topic of “EPC mechanism and business models”, it is worth highlighting two research directions in the future, which are:

(1) Better mechanism of applying EPC. The existing literature revealed two critical indicators—energy savings and economic revenue—for evaluating the success of EPC projects (by comparing the performance between ex-EPC and post-EPC projects) [55,74]. Therefore, significant efforts have been made to figure out how to achieve expected energy savings in EPC projects (for the aim of energy savings) (e.g., [32,54]) or how to achieve optimal energy savings (for the aim of maximizing economic benefits) (e.g., [43–55]). According to our review, prior studies largely highlighted achieving either energy savings or economic revenue when applying EPC, but seldom concerned the EU’s perceptions toward EPC project success. In fact, failure to consider the EU’s perceptions in EPC projects would cause ‘rebound effects’ (e.g., [76–78]), which are critical in affecting energy savings after energy retrofits [80]. For example, it was found that not all EUs satisfy EPC regulations, although EPC is energy-efficient, and one of the most critical reasons is that the EU’s activities and perceptions are ignored [76]. Therefore, a better and more reasonable mechanism for evaluating EPC projects is expected in the future.

(2) Optimal choice of EPC business models. Determining a reasonable business model has been looked as an important factor affecting the effectiveness of EPC projects [19]. Various EPC business models, including the Share Savings Model (SSM), the Guaranteed Savings Model (GSM), the Energy-cost Trust Model (ETM), and the Finance Lease Model (FLM), have been widely discussed and analyzed in existing literature (e.g., [3,16,19]). Given that the choice of EPC business models is

commonly regarded as a multicriteria problem, decision-makers' preferences/opinions in linguistic terms would be taken into account when choosing an EPC business model that is deemed suitable and applicable. Prior literature suggested that the choice of an optimal EPC business model would be dependent on various factors such as project stage, contract arrangement, financial condition of the EU, ESCO's technical ability, and EPC project's energy-saving requirements [27,35]. That is, different project settings would result in different choices of EPC business models. This is proven by a study of Liu et al. [80], which showed that the energy-cost trust model is best for a country or region when it is standing at the developing stage. Considering the increasing uncertainties inherent in the environment (both internal and external), it would be critical to make endeavors to investigate and determine an appropriate EPC business model under a given project setting [46,72,81]. In addition, the reasonable and effective choice methods can also help the participants of EPC projects find the optimal EPC business models smoothly [16]. The future research related to this topic would involve indicators and methods for EPC business model evaluation, innovation of existing EPC business models, adaptability of EPC business models, and performance evaluation of EPC business model application.

4.4.3. Research Trend of "Decision-making in EPC Projects"

In the future, three subtopics on "decision-making in EPC projects" should be studied:

(1) Cooperative and opportunistic behaviors and decisions in EPC projects. Two major clusters of stakeholders were identified by prior literature, i.e., the ESCO and the EU. Decisions between them are deemed critical to affecting the overall performance of EPC projects [82]. Although EPC has been commonly regarded as a mechanism (contract arrangement) able to achieve mutual benefits for both the ESCO and the EU [46,83], opportunistic behaviors can occur if inappropriately dealt with, which bring adverse impacts to the mutually cooperative relationship [80]. The cooperative and opportunistic behaviors and decisions in EPC projects have recently emerged as a research topic. For example, Zhou et al. [4] studied EU and ESCO's cooperative and competitive behaviors by developing a game theory model; similarly, Lu et al. [82] explored EU and ESCO's behavior decision-making problems in EPC project. We thus suggest more future studies on this topic, for example, by employing different perspectives (such as transaction cost theory and social exchange theory) for examining the partnering relationship between the ESCO and the EU. Such studies would contribute to maximizing stakeholder cooperation and simultaneously minimizing opportunistic behaviors in EPC projects.

(2) How would new stakeholders re-shape decision-makings in EPC projects? The existing literature told that the game theory has been widely employed for investigating the decision-making process among major stakeholders in EPC projects. Prior literature mainly investigated the decision-making process between the ESCO and the EU, such as Zhang et al. [34], Hannon et al. [21], and Deng et al. [43,44]. However, the negotiation about the energy-savings benefit allocation is actually a game process. Based on the Rubinstein bargaining model, Shang et al. [55], and thus explored such a bargaining process for obtaining an effective interval that satisfies both the ESCO and the EU. However, with the development and evolution of EPC businesses, new stakeholders would emerge and consequently play a role in affecting EPC projects performance [46]. According to Lu et al. [82], besides the ESCO and the EU, it is essential to consider the renters who are becoming more and more influential in EPC project implementation, particularly in building retrofit projects. In addition, Liu et al. [79] argued that all stakeholders' behaviors should be considered in EPC project operation and management process. Furthermore, with the increase of EPC in public buildings and multi-apartments, renters are becoming a new stakeholder of EPC projects [72]. The appearance of the renter in EPC projects tends to significantly affect stakeholder relationships and consequently reshaping the decision-makings in EPC projects. Therefore, how the appearance of new stakeholders reshape the decision-making in EPC projects can be a question deserves more research endeavors.

(3) The influence of symmetric/asymmetric information on decision-making in EPC projects. In the prior literature, continuous efforts have been made to investigate the decision-making process through either optimal decision theories or game theories (two-party game or three-party game)

(e.g., [25,50,59,84,85]). In these studies the role of information (symmetric/asymmetric) in affecting the decision-making process is highlighted. For example, according to Lu and Shao [50], the subsidies information on pricing released by the government will affect EPC projects' energy-efficient performance; and the information structure in EPC project also affects both the EU's and ESCO's energy-saving benefits and the whole EPC project's energy-saving performance [85]. Given that a core objective of applying the EPC mechanism is achieving optimal energy savings benefit allocation among major stakeholders [4], analysis of the influence of symmetric/asymmetric information on decision-making in EPC projects is believed to be a potential topic of great importance and needs more studies as well.

4.4.4. Research Trend of "ESCOs in EPC Projects"

Within the topic of "ESCOs in EPC projects", two major questions need to be explored:

(1) How to improve the EU's attitudes/cognitions toward the ESCO and EPC application? Previous studies indicated clearly that the attitude/cognition of the EU toward the ESCO and EPC application has been identified as a critical factor limiting the diffusion of ESCO and EPC application. For example, Zhang et al. [34] argued that insufficient social recognition of EPC is one of the problems faced by the ESCO; Kostka and Shin [42] advocated that the trust relationships between the EU and the ESCO is the base of EPC project implementation in China; and the findings of Lee and Dzung [36] proved that the negative attitudes of the EU would hinder the operation of ESCO in Hong Kong and Taiwan; besides, the EU's terrible cognitions to ESCO would hinder the diffusion of ESCO, demonstrated by evidence from Finland [35]. Considering that stakeholders' attitudes are influential in affecting the performance of EPC projects [74], it is therefore deemed that finding solutions for improving the EU's attitudes/cognitions toward the ESCO and EPC application would be a prosperous topic in the future.

(2) How to develop appropriate ESCO operating models. In any EPC project, the majority of activities regarding energy saving, such as energy auditing, financing, energy-saving designing, equipment purchasing, and energy accounting [4], are closely related to the ESCO. However, there can be various models for operating the ESCO. According to Hannon and Ronan [86], three ESCO models can be chosen by the Britain authority: the local authority owned 'arm's-length' model, private sector owned concession agreement model, and community-owned run model. This tells us that different ESCO operating models indicate different relationships between the ESCO and the EU, and thus would be influential in affecting the overall performance of EPC project implementation [3,48,52]. At present, limited research efforts are devoted to this research problem. In the future, it is suggested to develop appropriate ESCO operating models by considering major project environment such as project background and characteristics, and nature and preferences of the EU. Future research may also involve evaluation of the developed ESCO operating models.

4.4.5. Research Trend of "Risk Management in EPC Projects"

As for the topic of "risk management in EPC projects", two questions are unsolved and should be answered in future:

(1) How to effectively prevent risks in EPC projects? Previous studies have made considerable efforts into identifying and evaluating the risks in EPC project implementation, which are critical to ensuring project success. For example, Hu and Zhou [31] identified major EPC project risks including engineering risks, the political and legal risks, technology risks, management risks, financial risks, project quality risks, and client risks. Qian and Guo [32] explored the uncertainty of risks in EPC, and advocated that more research is deserved to studying the fluctuations of future energy price, the unpredictable accident and energy saving shortfall. Lee et al. [33] evaluated the influence of critical EPC project risks, such as potential payment default of EUs, vague of baseline measurement, and overspending in EPC projects. However, identification and evaluation of EPC project risks is not a one-off process [31,53]. Besides, project risks may vary depending on various factors, such as the project stakeholder, project characteristics, internal environment, and external environment [8,61]. According to our literature review, although mostly researchers argued that it is important to identify and evaluate

risks in EPC project (e.g., Hu and Zhou [31], Lee et al. [8,33], and Maria and Reinhard [53]), they seldom mentioned how to address those risks effectively. It is thus essential to continuously develop effective methods for risk identification and evaluation, with the ultimate purpose of preventing risks in EPC projects.

(2) How to deal with EPC project risks from a systematic perspective? Although several major risks threatening EPC project implementation are identified, such as energy price fluctuation, energy savings, accidents, the effectiveness of managing such risks can still be problematic [32]. A major cause leading to the difficulty of managing risks effectively lies in that different stakeholders perceive project risks differently due to stakeholders' varying attitudes toward risk assessment and evaluation [8,30,53]. This explains why, even for the same risks, different project stakeholders would make different, sometimes even opposite judgment and evaluations. For instance, according to Lee et al. [33], the ESCO would perceive risks covering EU's payback periods, repay ability, possible and payment default as important, while the EU might concern ESCO's equipment quality, project complexities, and the financing ability. In this regard, how to assess EPC project risks by integrating viewpoints from different stakeholders is critical for project success, but still challenging (e.g., [5,31,61]). In a recent study by Winther and Gurigard [74], the results from a pilot EPC project in Norwegian implied that risks considered by EU and ESCO were very different. Therefore, it is essential to answer "how to deal with EPC project risks from a systematic perspective?" Further studies can be directed to examining causal relationships among EPC risks through, for example, a system dynamics approach or revealing the dynamic evolution of EPC project risks based on the evolutionary game theory.

5. Conclusions

Increasing demand of applying energy performance contracting (EPC) for energy retrofits and conservation has resulted in a significant amount of publications over the past decade. Employing a review-based approach, this paper provides a holistic view on the research in EPC through analyzing 127 journal papers published from 2008 to 2018. Based on the analysis and discussion, the major EPC research trends were identified. The main conclusions of this paper are as follows.

- (1) In the past decade, there is a trend of gradually increasing research interests in EPC issues.
- (2) Our findings reveal that the case study, theoretical/mathematical analysis, and survey were almost equally applied in EPC research in the past decade. Modeling and simulation methods, descriptive analysis, and statistical analysis are the three major clusters of methods for data analysis.
- (3) The thorough review of the sample papers identifies five major topics among existing EPC research over the past decade, which include 'implementation of EPC projects', 'EPC mechanism and business models', 'decision-making in EPC projects', 'ESCOs in EPC projects', and 'risk management in EPC projects'. Among them, the two topics of 'implementations of EPC' and 'EPC mechanism and business models' have been dominant.
- (4) Based on the analysis of the five EPC research topics, the future research directions/trends are proposed and discussed. The trends of EPC research in future cover five directions and twelve subtopics in total. Firstly, three research trends exist on the topic of "implementation of EPC projects", including 'An effective system for measuring and verifying the performance of energy saving through EPC', 'Application of EPC in the residential sector', and 'The government's role in promoting EPC application'. Secondly, two directions of "EPC mechanism and business models", covering 'Better mechanism of applying EPC' and 'Optimal choice of EPC business models'. Thirdly, trends of "decision-making in EPC projects" are 'Cooperative and opportunistic behaviors and decisions in EPC projects', 'How would new stakeholders reshape decision-makings in EPC projects' and 'The influence of symmetric/asymmetric information on decision-making in EPC projects'. Fourthly, there are two directions of "ESCOs in EPC projects", including 'How to improve the EU's attitudes/cognitions toward the ESCO and EPC application' and 'How to develop appropriate ESCO operating models'. Finally, two directions in topic of "risk

management in EPC projects” are ‘How to effectively prevent risks in EPC projects’ and ‘How to deal with EPC project risks from a systematic perspective’.

The findings can be informative and useful for both EPC researchers and practitioners. For researchers, the work of this paper can be valuable for guiding future research in EPC, and would be particularly helpful for researchers who are keen to open a new window of investigating EPC issues. As for practitioners, they can understand the latest research interests in EPC issues, through which to bridge their practice with research for enhancing the practices.

Nevertheless, there are also limitations for the present study. Firstly, it is appreciated that 127 papers referred herein may not contain all related publications of EPC from 2008 to 2018, although those journal papers are representative to reflect the general trend of EPC research. Secondly, in this study, we mainly use context analysis to facilitate the literature analysis. There is a trend that some scholars are beginning to use bibliometric analysis to show the complex relationships among major papers in a specific subject. Thus, it would be valuable to expand this research by a bibliometric analysis method in the future.

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