



Challenges and strategies for energy performance contracting: A critical review

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Abstract

Energy performance contracting (EPC) has been implemented as a turnkey solution to enhance the energy efficiency of building systems and fixtures. The two most common types of EPC-guaranteed savings contracts and shared savings contracts-are widely applied in the industry, with their selection primarily depending on stakeholders' risk tolerance and the availability of external financing. EPC involves multiple key participants, including the government, third-party financiers, building owners, and energy service companies (ESCOs). The relationships among these stakeholders vary based on the contract type: in a guaranteed savings contract, the owner has a direct financial relationship with the third-party financier, whereas in a shared savings contract, the ESCO assumes this role. This paper provides a critical review of previous studies on EPC, categorizing them into four key areas: (1) challenges in EPC adoption, (2) critical success factors, (3) diffusion strategies from different stakeholder perspectives, and (4) a stakeholder relationship framework linking key success factors and strategies. By analyzing these aspects, this review aims to inform potential investors and contractors about essential considerations for EPC implementation while examining the stakeholder dynamics within EPC projects.

Keywords: Energy performance contracting, stakeholder relationship, challenges, key success factors, strategies

1. Introduction

Reducing energy consumption and promoting sustainable development have become urgent global priorities in the 21st century. The building sector alone accounts for 32% of the world's total final energy consumption^[1], with residential and commercial buildings contributing approximately 35% of total primary energy consumption in the U.S. in 2016^[2], a figure that has since increased to over 70%^[3]. According to the National Institute of Building Sciences' *World Building Design Guide*, occupancy costs represent 92% of a building's total life-cycle costs, while initial and operational costs account for just 2% and 6%, respectively^[4].

The rapid advancement of artificial intelligence (AI) has significantly enhanced building performance optimization in recent years^[5-7]. One such approach is energy performance contracting (EPC), which offers comprehensive technical solutions to reduce building energy consumption and costs through efficiency improvements and on-site generation technologies^[8-11]. Energy service companies (ESCOs) play a key role in EPC by optimizing building designs, upgrading equipment, and refining operational strategies. Emerging in the late 1980s, ESCOs initially provided self-financed energy services to large corporations^[12]. The success of early EPC projects, such as those conducted by Lawrence Berkeley National Laboratory^[13], prompted federal and state governments to promote EPC adoption, attracting increasing public interest^[13].

EPC contracts generally fall into two primary categories, guaranteed savings contracts and shared savings contracts (Table 1). The choice between these models depends primarily on risk tolerance and external financing availability (Figure 1).

Guaranteed savings contract: Predominantly used in government institutions, this model ensures a minimum level of savings during a fixed contract period. The ESCO provides energy efficiency improvements, and if actual savings fall short, the ESCO covers the



shortfall. However, if savings exceed expectations, the ESCO does not receive additional benefits^[15]. Financing is typically arranged directly between the owner and a third-party financier, with the ESCO potentially facilitating the arrangement^[16].

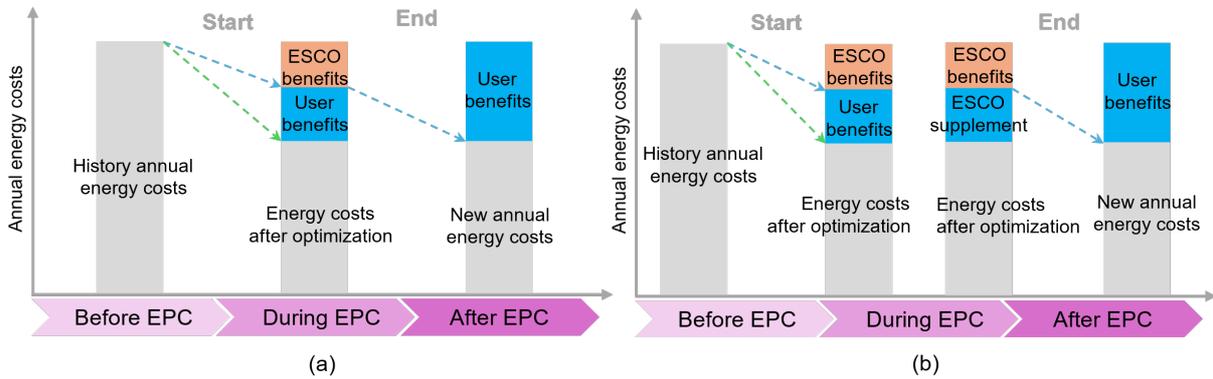


Figure 1. Performance contract classification. (a) Guaranteed savings contract; (b) Shared savings contract^[14]. EPC: energy performance contract; ESCO: energy service company.

Table 1. Difference between the two common types of EPC.

Contract type	Capital investment	3 rd financier	Savings allocation
Guaranteed savings contract	Customer	Loan to customer	Fixed payment schedule: ESCOs cover the shortfall in savings and have no added benefit if savings are exceeded.
Shared savings contract	ESCOs	Loan to ESCO	A minimum fee is combined with either a fixed percentage of the savings or a portion. ESCO and the customer share the added benefit if savings are exceeded.

EPC: energy performance contract; ESCO: energy service company.

Shared savings contract: Less commonly used, this model requires the ESCO to provide the capital investment, with cost savings shared between the ESCO and the building owner. Payment structures can vary, including a fixed percentage of savings, a minimum fee plus a share of savings, or a progressively adjusting fee. The ESCO may also secure financing from a third-party financier, and any excess savings are shared between the ESCO and the owner^[16].

Figure 2 illustrates the cash flow mechanisms for both guaranteed savings contract(a) and shared savings contract(b). The two contract types differ in capital investment, third-party financier, and savings allocation. In a guaranteed savings contract, the owner provides capital investment; the third financier signs the loan contract with the customer and loans money to them; if savings are below the expectation, the ESCOs are requested to cover the shortfall, while there are no additional benefits for ESCOs if savings exceeded. In a shared savings contract, ESCOs provide capital investment and have the direct loan contract with the third-party financier; the ESCOs are paid with a minimum fee plus a share of savings. If savings exceed expectations, ESCOs and the customer share the financial benefits.

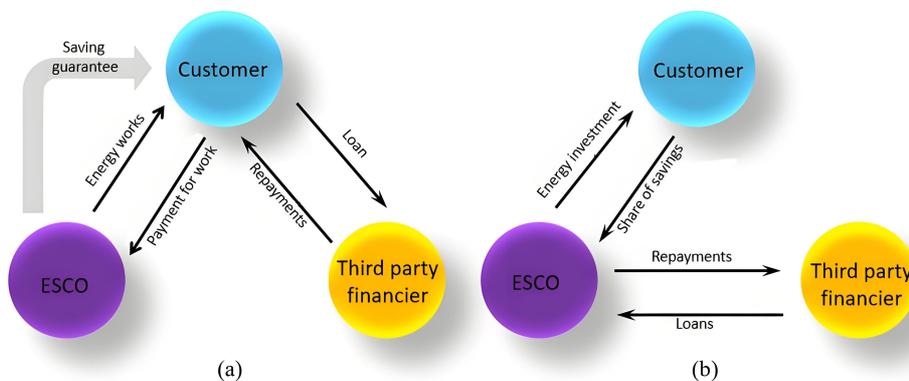


Figure 2. Cash flow in different EPC types: (a) Guaranteed savings contract; (b) Shared savings contract. ESCO: energy service company.

Many parties are involved in the adoption activities, of which four parties play more critical roles, including the government entities, building owners, ESCOs, and third-party financiers^[17,18]. Figure 3 presents the stakeholder relationships in EPC adoption. The government provides preferential policies to the developing ESCOs, regulates the financial market, and publishes guidance documents to help owners familiarize with EPC contracts^[19]. The relationships among the parties in EPC vary depending on contract type. The third-party financier has a direct relationship with the owner in the guaranteed savings contract, while the ESCO may receive financing directly from the financier in the shared savings contract. Therefore, the attitudes of owners, ESCOs, and governments towards energy efficiency activities directly affect the feasibility and performance of EPC^[20].

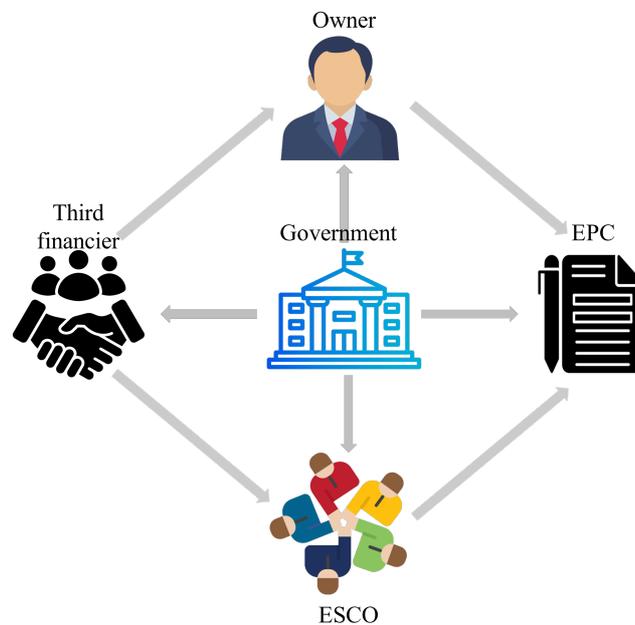


Figure 3. Stakeholder diagram in the adoption of EPC. EPC: energy performance contract; ESCO: energy service companie.

While EPC has been successfully adopted in many countries and organizations, some countries have encountered political and policy-related challenges. For instance, EPC adoption in Norway failed due to three primary issues: (1) lack of public policy incentives to promote energy efficiency, resulting in low demand for energy-saving solutions in buildings; (2) limited government intervention in regulating the building industry, as authorities prioritize economic incentives over building codes; and (3) a conservative and inflexible construction industry, which resists adopting innovative energy-saving technologies. In the absence of strong policy support and regulatory frameworks, EPC adoption struggles to gain momentum, as seen in the Norwegian case^[21].

Through a comprehensive review of existing EPC literature, this paper aims to identify key stakeholder relations in EPC projects, analyze challenges ESCOs and owners encounter in EPC adoption, examine critical success factors and EPC diffusion strategies to overcome these challenges, and provide actionable recommendations for stakeholders, particularly potential EPC adopters and subject matter experts, to ensure the successful implementation of EPC projects.

2. Data and Method

Given the limited exploration of EPC in existing studies and the abundant literature available on Google Scholar, this study collects the publications based on Google Scholar and filters the high-quality data manually. The search keywords include *energy performance contract*, *energy performance*, *ESCOs*, *energy efficiency and contract*, and *performance contracting*. A total of 40 relevant papers were selected from the following journals: *Building Research & Information*, *Building and Environment*, *Energy Policy*, *Energy*, *Energy Efficiency*, *Journal of Cleaner Production*, *Journal of Property Investment & Finance*, *Energy and Buildings*, *Facilities*, *Construction Law Journal*, *International Journal of Service Industry Management*, *Journal of Construction Engineering and Management*, *Review of Economics and Statistics*, as well as proceedings from relevant research conferences.

This review systematically examines EPC applications across representative countries and analyzes challenges from different perspectives. Subsequently, the essential factors and future development strategies are explicitly analyzed, aiming to enhance stakeholder collaboration and EPC adoption. The remainder of this paper is structured as follows: 1) current challenges in EPC adoption; 2) identification and summary of the key success factors (KSFs) influencing EPC adoption; 3) EPC diffusion strategies from perspectives of government, owners, and ESCOs; and finally, 4) A stakeholder relationship framework, mapping KSFs, stakeholders, and strategies.

3. EPC Adoption Worldwide

To mitigate climate change and optimize building performance, many countries actively promoted EPC and established stakeholder collaborations^[22]. The global distribution of EPC adoption is shown in Figure 4. Key contributors to EPC implementation include China, the United States, Canada, Spain, England, etc. In the U.S., EPC is predominantly adopted by government and institutional clients, with guaranteed savings contracts being the most common model. By comparison, state-owned industrial enterprises in China receive financial support more easily than small- and medium-sized ESCOs, leading the Chinese government to actively promote shared savings contracts^[24].

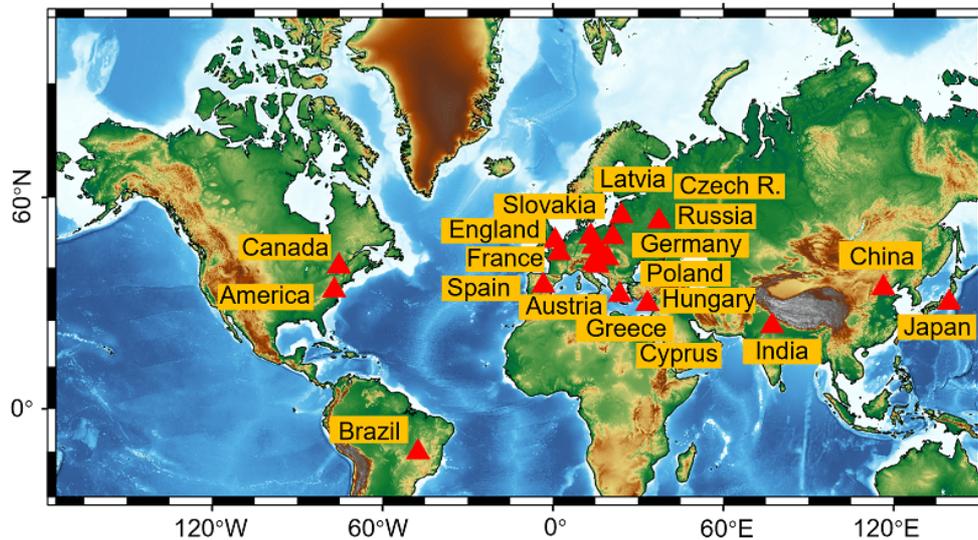


Figure 4. The countries referring to the EPC^[23]. EPC: energy performance contract.

3.1 EPC adoption in the United States

Higher education institutions in the U.S. have relatively steady, long-term strategic facility plans, making them suitable candidates for EPC adoption.

- Kentucky Community and Technical College System in Kentucky: In December 2011, a 13-year EPC contract worth \$4.66 million was implemented to improve lighting, water, electrical, mechanical, and control systems at multiple colleges, saving \$480,000 annually. By the end of the contract, cumulative operational savings will exceed the initial project cost^[25].
- Kutztown University (PA): The university upgraded infrastructure to generate energy and operational savings. This EPC project was installed with electric, steam, water, and gas utility meters, Enhancing the current digital control and utility monitoring systems. The project cost \$6.6 million and was estimated to save \$718,000 annually over a 15-year term of the contract^[26].
- Oregon State University: Signed an EPC (guaranteed savings) contract in 2004 for the Hatfield Marine Science Center building with 250,000 square feet. The \$310,318 project spanned 11.3 years, receiving support from the Department of Energy's Business Energy Tax Credit and Energy Loan Programs. The Hatfield Center partnered with a for-profit business to transfer the project's tax credit in exchange for a cash payment. The project involved upgrading lighting and optimizing the energy management system, resulting in annual energy savings exceeding 277,000 kWh, valued at over \$15,600 annually^[27].
- University Medical Center of Southern Nevada (Las Vegas): From 2011 to 2013, Ameresco executed a \$47 million EPC project to upgrade lighting, HVAC systems, and air handling units, generating \$4 million in annual savings. The project also aimed to reduce 304,000 tons of carbon emissions, significantly reducing fossil fuel dependency. Another EPC project completed by Ameresco and Syracuse Housing Authority was the apartment retrofit program in upstate New York, which was expected to provide nearly \$5 million in funding for several of the agency's apartment complexes. The U.S. Department of Housing and Urban Development incentivized efficiency upgrades, projecting savings exceeding \$7.5 million over a 16-year agreement^[28].

3.2 EPC adoption in the United Kingdom.

Early research on EPC adoption in the UK highlights its potential for driving the transition to a low-carbon economy. However, widespread adoption remains challenging due to the involvement of multiple stakeholders and split incentives. The paper investigated the impact of EPC on public energy conservation in the UK and proposed a model that could simplify the process of negotiating, developing, and implementing EPC projects.

Many initiatives to adopt EPC have been taken in the public health domain, particularly for hospital projects. For instance, St George's Hospital (London, Britain) enhances building performance by optimizing various components, e.g., absorption chillers, solar photovoltaic, combined heat and power boilers, steam system modifications, and a range of heating, ventilation, and air-conditioning, aiming to reduce over 6,000 tons carbon emissions. This EPC made a net saving of over £1.02m per year during its 15-year life (2014). Stewarts Hospital with ESCO Dalkia signed the €1.5 million shared savings contract, including installing a heating boiler, a new main distribution board and emergency generator, controls, heating zones, an energy monitoring system, and energy-efficient lighting. ESCO was responsible for invoices monthly to cover the cost of energy supply, financing, O&M, and energy management under the 15-year contract. It is expected to save €100,000 annually. A six-year EPC between E.ON and Newham University Hospital was amongst the very first of the London Development Agency's RE: FIT program; by implementing the energy efficiency measure in public buildings, this project aimed at reducing capital's carbon emissions. More than 940,000 kWhrs energy consumption was reduced each year. The project was anticipated to achieve cost recovery within seven years while reducing the hospital's carbon emissions by over 3,000 metric tons during the same period. Additional planned upgrades to lower the hospital's energy consumption included replacing the Air Handling Plant and implementing Dry Air Chilled Heat Recovery systems^[29].

Another research regarding the energy consumption of existing buildings in the UK reveals that energy efficiency has gradually become one primary consideration in their industry because of the climate and environmental issues^[30]. It also pointed out that the Energy Performance in Buildings Directive and the Energy Services Directive could become the primary driving force to promote EPC development in the UK. Still, the final performance and effect were unclear and would depend on the details of the Directives' implementation. An innovative measurement approach was proposed to successfully fulfill the Directives' energy-saving requirements, which could compare the actual energy savings with the theoretical saving amount and identify the shortcomings of EPC projects^[31]. Accordingly, practical measurements could improve the performance based on the identified gap.

Despite EU influence, UK energy efficiency efforts have yet to meet EU targets, particularly for existing buildings. Various methods and aims with different kinds of policies and regulations exist in the UK to encourage users to reduce energy consumption^[32]. Study revealed that long payback periods, insufficient government support, and lack of leadership are barriers to EPC development^[33].

3.3 EPC adoption in China

China's EPC market has grown significantly since the 1990s, emerging as a key strategy for improving energy efficiency^[34]. Studies revealed that over 90% of operational buildings in China fail to meet the energy conservation requirements, and the incorporation of EPC in the building industry was aimed at significantly enhancing building usage efficiency^[35]. Accordingly, many studies have been conducted on the effectiveness and applications of EPC in China. Pamela Youde Nethersole Eastern Hospital (Eastern Hospital) in Hong Kong worked with the local contractor and executed a guaranteed savings contract to develop a comprehensive energy management scheme. The contractor guaranteed a 12% annual reduction in energy costs over six years, amounting to a yearly savings of HK\$5 million, based on the total energy expenditure of HK\$55 million in 1997^[36].

Previous studies have analyzed the possible risks of adopting EPC and provided a quantitative evaluation approach to reduce the risks of EPC^[37]. How to properly apply the EPC mechanism in the building industry was studied, and 21 essential factors to promote EPC in Chinese building projects were identified^[38]. This study examined various aspects of the EPC industry, including project organization processes, financing strategies for hotel retrofit projects, knowledge and innovation in EPC, sustainable development and strategic implementation, contractual arrangements, and the influence of the external economic environment. Another research focused on internal and external factors influencing the successful deployments of EPC projects^[39]. A total of 23 factors were analyzed in this research, and suggestions for improving the development of EPC were proposed.

The research focused on the effectiveness of EPC in saving energy for nationwide emission trading scheme projects in China^[40]. It studied reasons leading to the unsuccess of EPC projects and put forward suggestions on how to manage existing EPC projects effectively. A model based on the Analytic Network Process was developed to incorporate the EPC mechanism into sustainable building energy efficient retrofit (BEER) projects in China^[41]. With the application of the EPC mechanism, BEER projects are demonstrated to be capable of optimizing the operation performance of high-energy-intensity buildings. A study was conducted about different kinds of EPC schemes, such as guaranteed saving schemes, shared saving schemes, and energy cost hosting schemes^[42]. The energy cost housing scheme was the most suitable business model because it could produce maximum profit benefits to stakeholders of EPC projects under this scheme.

4. Challenges

The adoption of EPC faces both internal and external barriers. These challenges are categorized into seven key areas to illustrate the current state of EPC implementation.

- Internal challenges include organizational, contractual, financial, and operational issues, such as the absence of standardized contracts, unsuitable financing mechanisms, inefficient management, and insufficient training and awareness programs.
- External challenges stem from economic and market risks, public sector and policy barriers, and cultural diversity. Factors such as

high transaction costs, fluctuating interest rates, energy baseline uncertainties, and differing cultural perceptions of EPC further complicate adoption.

A detailed summary of EPC risks is presented in Figure 5.

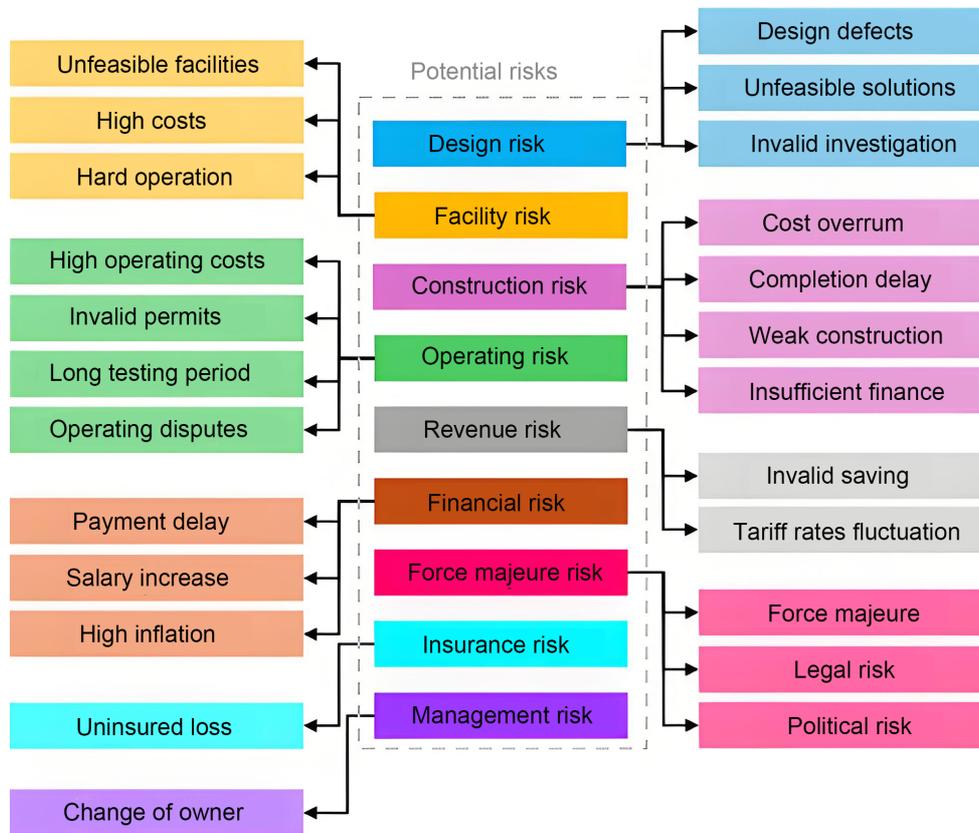


Figure 5. Potential risks for EPC^[40]. EPC: energy performance contract.

4.1 Organizational issues

Organization-related matters are inherent to EPC implementation. When the upper management only has limited knowledge about EPC, they are prone to worry about the feasibility of the project, complexity, long payback period, fewer demonstration projects by ESCO, and ESCO’s financing ability^[19,43-45]. Additionally, inefficient managerial practices-such as lack of leadership commitment, inadequate awareness, and insufficient employee training and motivation-further hinder EPC adoption^[19].

4.2 Contractual issues

EPC-related contractual issues primarily arise from the lack of standardized agreements and limited empirical studies. EPC contracts vary significantly across commercial, residential, and healthcare sectors, often focusing on specific system components such as lighting, HVAC, or industrial processes^[19,44]. Due to this lack of uniformity, some contracts are loosely structured, making terms unclear and inconsistent. A major challenge is contract duration-if too long, it reduces bidding competitiveness; if too short, it increases loan risks^[45-47]. Information imbalances between the owner and ESCO about the different retrofit expectations and shared benefits are challenging to remove. The client (the owner) does not feel they have sufficient information to choose the best option.

To address these issues, three critical contract components must be carefully considered:

(1) Investigation. Due to the complexities of the dynamic project environment, uncertainties in the investment returns exist during the EPC implementation. Accordingly, the investment decision-making process refers to tradeoffs^[48]. Generally, high investment in renewable energy technologies corresponds to more desired energy conservation. The investment strategy is based on getting the highest return on a lump sum investment^[49]. However, when investing, the ESCOs could not fix the savings in each operation period. Consequently, a tradeoff concern within the investment mainly comes from two extremes. The ESCOs cannot afford colossal investigation, whereas either overestimated energy-saving reports or an unforeseeable decrease in energy price may block the expected energy-saving achievement^[50]. Also, there is a maximum energy-saving amount for existing buildings. The ESCOs are cautious about choosing proper conservation technologies since relevant costs are covered by energy conservation^[51]. On the other

hand, ESCOs would not like to make an investment that is too low. If the actual energy savings fall short of the guaranteed amount, the ESCOs compensate the owners for the difference. Conversely, if the energy savings exceed expectations, the ESCOs share the additional revenue with the owners based on a predefined percentage. The ESCOs need to afford the initial investment in renewable energy technologies, guaranteeing the benefits can last for the project's lifetime and cover the total investment. According to the estimation, the ESCOs would select a stable investment scheme that comprehensively considers the potential losses and financing benefits to achieve the desired conservation goal.

(2) Contract term. Stakeholders in the market have not determined the lack of widely recognized standard results in the contract contexts. The ESCOs benefit greatly by adding longer terms to the contract, whereas the owners prefer simplified contexts regarding their rights and interests. Additionally, shorter contract terms for market competition are another factor that needs to be considered by the ESCOs^[46]. Simultaneously, several regulations should be followed: the Energy Policy Act^[52] requires that the most extended periods for the legal contract term last for 20 years and that local governments have authorized relevant legislation. In this context, the EPC contract should be determined by stakeholders according to actual situations.

(3) Guaranteed (or shared) saving design. Typically, the guarantee (or shared) design clauses and subsidies listed in the contracts can directly remove potential risks. For example, Pollio^[53] indicated that one of the benefits of the proposed guarantee is to mitigate the negative impact of uncertainty risks on investment. Brandao and Saraiva^[54] viewed the minimum traffic guarantee as an option to evaluate the role of governments in public-private partnerships. The ESCOs were motivated to explore more efficient energy conservation solutions, and the well-designed saving guarantees allowed stakeholders to make efforts for the same goals^[55]. Generally, the main tradeoff concern within the guarantee comes from two extremes^[56]. On the one hand, ESCOs are prone to avoid risks. Either the unforeseeable decrease in energy prices or the ineffective energy-saving technologies could block the expected energy-saving achievement. As a result, they tend to make conservative saving guarantees. Simultaneously, ESCOs need energy-saving guarantees to obtain financial support, ensuring that the benefits can simultaneously cover the project's period and total investment. Besides that, a high guarantee increases the competitiveness for ESCOs to win the bid. Thus, the guarantee would stay in a suitable interval comprehensively considering the benefits, potential losses, and bidding competitiveness.

4.3 Financial issues

One of the significant concerns of building owners is the financing mechanism. There are four types of financing forms: self-financed by an organization (owner), ESCO-financed, third-party financed, and lease-purchase agreements^[12]. Lack of capital costs can lead to the failure of EPC promotion^[44]. The recognized way is that the ESCO arranges third-party financing. Large financial institutions usually lend the project funds, while some cases occur when facility owners and ESCOs provide the funds. Furthermore, the debt structure may vary based on whether the financing is off the balance sheet and does not accrue toward the debt limits.

This financial mechanism issue is vital during the initial negotiation between the owner and the ESCO. Measurement and verification (M&V) is an ongoing measurement and audit activity that aims to evaluate the progress of energy conservation goals predicted and listed in the contract and provide an efficient introduction for any energy retrofit. It is estimated that the annual cost savings of M&V vary from 2% to 10%^[19].

How to balance the M&V costs and precisely verify the savings can be a considerable challenge^[19,41,57]. Once the project is delayed, which may be caused by the owner or contractor, it can bring much financial pressure to the whole project (e.g., construction interest, remobilization). Based on the open market, ESCOs encounter lots of competition, and the competitive bidding will continue to encourage them to make efforts on energy conservation^[58].

4.4 Economic and market risks of EPC

Transaction cost is usually a costly issue in the adoption decision. Asset specificity and the standardization of performance contract formulation and verification processes significantly impact transaction costs. They interact closely and influence each other. Especially for small-scale projects, collecting explicit information is time-consuming and labor-intensive for performance contracting and validation. Thus, they should be balanced during the decision-making process^[44,45,59,60].

Except for that, determining the baseline is one of the essential challenges for the economic consideration of EPC. The energy baseline refers to acceptable thermal comforts, weather conditions, building schedule, etc. Without the authorized baseline regarding materials, labor management, and energy usage, it is hard to verify whether energy savings have been achieved^[44,45]. Thus, contracting parties suffer from the variation risks regarding energy costs and demands, and relevant baselines should be changed according to actual situations. By comparison, these risks are afforded by the ESCOs in the guaranteed saving model. Besides, the confirmation of the energy baseline encounters a substantial amount of uncertainties due to market fluctuation, such as the interest rate and energy price^[16,51,61-63]. Available technology and know-how related to EPC also influence EPC's adoption and performance, such as poor system/equipment performance and wrong equipment sizing^[45,55].

4.5 Operational issues

During the operation of EPC, there are two common issues: operational and managerial. Lack of operational resources (including time, cost, and skills) often jeopardizes the execution of EPC. Time and cost resources during the operation could be affected by many factors. For instance, the annual M&V costs vary a lot and can cause overruns for consecutive years. How to avoid them by using proper tools and techniques is of vital importance^[19]. Besides, the commitment of senior management plays a key role. The lack of efficient managerial actions not only decreases the morale for innovation but also hinders self-improvement within an organization^[16,19,59,64,65]. In addition to the unexpected fast rate of equipment degradation caused by poor maintenance and changes in baseline conditions, a load on system conditions may result in unusual consumption patterns and increase operational risks^[45].

4.6 Barriers in the public sector & policy

There are many obstacles originating from the public sector or government, such as the time lag of the policy execution, the extent of their support for new policy strategies, and complex procurement rules. The public procurement procedures in the use of Portugal are complex and time-consuming, which results in an increment of transaction costs and undermines their feasibility^[59]. It can be seen that regulatory policies often find it hard to meet firms' demands and social requirements.

In some countries, there is a lack of government support for energy performance contracting. Safety and reliability concerns can hinder the incorporation of new energy-efficient technologies. Many companies are not interested in reducing energy use or are even opposed to such measures because they fear a loss of income. The lack of quantitative measures/targets and the lack of information from monitoring and verification of actual energy savings are found in the evaluations of the energy efficiency policy instruments applied across Europe, the U.S., China, and Japan^[19,36,55].

5. Key Success Factors

After reviewing the challenges and barriers ESCOs face, we are interested in finding measures to overcome the abovementioned obstacles and support the successful adoption of EPC. According to the literature review, seven critical factors are identified: government assistance, contracting, economic and market-related factors, leadership and team, project development, financing, and partnership. Each main category has 2-6 sub-factors. Based on the frequency of being mentioned, five highly mentioned factors, namely, the five most important factors, are abstracted and presented in [Table 2](#). They are the energy policy of the local government, standard protocols for maintenance & verification, sustainable development strategy, available financing channels, and accurate M&V ([Table 2](#)).

Table 2. The critical success factors of adoption EPC and its categories.

Groups	Tag	Key Factors	Stakeholder	Reference
1. Government support	Government plays a critical role in paving the road for EPC adoption and support for EPC success. They provide guidance, practices, and legislation.	1-1 Energy policy of the local government	Government	[13,57,66]
		1-2 Sound system of legislation and regulation	Government	[66]
		1-3 Supporting finance and taxation policy	Government	[13,65,66]
		1-4 Clients' and ESCOs' awareness of sustainability	Government, ESCO, owner	[41,57,63]
		1-5 Training programs to contract users	Government, ESCO, owner	[64]
2. Contracting factors	The decision to make the EPC contract should be prudent. Fair principles, balanced power, and reasonable risk management mechanisms influence the success of EPC.	2-1 Standard protocols for maintenance & verification	Owner, government	[19,41,66]
		2-2 Contract period	ESCO, owner	[47]
		2-3 Savings share	ESCO, owner	[67]
		2-4 Task and risk allocation	ESCO, owner	[41,66]
3. Economic and Market-related	Dynamic economic environment and market bring uncertainties. Fast upgrading	3-1 Economic environment	Government, 3 rd financier	[15,41]
		3-2 Available technology	Government	[41,57]

factors	of technology and increased uncertainty in energy prices add to the risks of EPC.	3-3 Energy price ascending	Government	[15,61,63]
4. Leadership and team factors	Once the clients choose the EPC and ESCO, they have high expectations of ESCO. Thus, ESCO should show its ability to arrange the contract. ESCO's Effective cross-communication, good leadership, and risk control make them competitive.	4-1 Clients' awareness of EPC	Owner	[15,41,66]
		4-2 Leader's organizational skill	ESCO, owner	[41]
		4-3 Communication skill	ESCO, owner	[41,64]
		4-4 ESCO's capacity for energy audits	ESCO	[67]
		4-5 ESCO's competitive capacity	ESCO	[16,66]
5. Project development factors	The goal of EPC is to improve sustainable development in the building industry. Thus, the sustainability issue is paid more attention when considering the success of EPC.	5-1 Sustainable development strategy planning	ESCO	[13,41,57,66]
		5-2 Control mechanism of development strategy	ESCO	[41,42]
6. Financing factors	The success of an EPC is closely linked to the availability of third-party financing and the ability to self-finance.	6-1 Available financing channels	ESCO, government,3 rd financier	[13,19,41,66]
		6-2 Credit and reputation of ESCOs and clients	ESCO, owner	[38]
7. Partnership factors	Owners and ESCOs find the importance of strategic alliance and partnership. Coalition and partnership can help play their strong points.	7-1 Mutual Trust	ESCO, owner	[16,41,57]
		7-2 Transparent information delivery	Government ESCO, owner	[41,63]
		7-3 Effective coordination	ESCO, owner	[36]
		7-4 Project objectives control mechanism	ESCO, owner	[41,57]
		7-5 Accurate M&V	ESCO	[16,41,57,66]
		7-6 Operation in good condition	ESCO	[57,59]

EPC: energy performance contract; ESCO: energy service companie; M&V: measurement and verification.

The energy policy of local authorities demonstrates how the government supports this type of contract at a legislative level, which is developing a foundation for the EPC. Standard protocols for maintenance and verification can provide ESCOs with the criteria to follow. With the standardization of the protocols, owners and the financial community can better understand EPC, and even the disputes between owners and ESCOs may decrease. Available financing channels are considered the essential factor associated with EPC application. The owners attach importance to the ESCOs' financing capabilities because ESCOs take the most responsibility for funding and financing. Accurate M&V enables ESCOs to quantitatively analyze the energy conservation potential, control equipment performance, and extra conservation components, which could expand the savings to a maximum level. Government attitudes, contract contexts and organizational management are the essential factors affecting the promotion of EPC. Firstly, it is crucial to design a suitable framework to encourage the participation of stakeholders. Additionally, promoting the cooperation of governments and expanding the EPC market are necessary.

6. Diffusion Strategies

For the successful adoption of EPC, the government, ESCOs, and owners all need to make efforts to enhance the current energy efficiency in the building industry.

- Governments should introduce economic and financial incentives, remove institutional barriers, and support EPC initiatives through policy frameworks.

- ESCOs must focus on self-improvement, technological advancement, and competitive market positioning.
- Owners should be educated about EPC benefits, increasing awareness and adoption rates.

6.1 Government policies and support for EPC

The attitude of governments toward EPC promotion is critical, as it provides preferential policies to the developing ESCOs and publishes the relevant guidebooks and legislation. Although the U.S. federal agency, EPA, has been providing relevant evidence and guidelines, government-related areas can still be improved to overcome the current barriers to EPC development, such as official incentive documents, incentive policies, and institutional obstacles^[68].

(1) Reinforcement of official incentive documents and programs

Starting new practices like EPC is often more complex in conservative and risk-averse countries. Therefore, The government would revise procurement regulations to eliminate this cultural barrier and expand the ESCO market within the public sector^[19,46,55,63]. Providing sound legislation to protect this booming industry is essential for a government. The government can issue and establish programs to promote energy saving and efficiency in construction projects. For instance, several voluntary assessment schemes exist in the United States, such as Leadership in Energy and Environmental Design, CHEERS and Green Building Programs, Energy Star Program, Home Energy Rating System, Builder Option, and Voluntary product labeling. Similarly, the above incentive programs can encourage clients and building owners to adopt energy-efficient fixtures and systems. A government should also support technological innovation to accelerate industry development and improve the sustainable awareness of both ESCOs and owners.

(2) Economic and financial incentives policies

The governments play the role of policymakers in creating a suitable investigation environment and expanding the green building market demands to attract investors, such as energy price controls, tax deductions, subsidies, etc.^[45,63]. Setting an optimal price for energy and providing official procurement programs to the private sector can improve their incentive to participate in the EPC execution. Also, the government can assist in exploring and developing financing channels in financial institutions and commercial banks, and preferential policies can be issued for private sectors, such as low-cost loans and special purpose funds.

High transaction costs can be one of the impediments hindering the adoption of EPC. The standardized transaction procedure and cost can facilitate the adoption of EPC. Thus, reducing the transaction cost to a reasonable level is essential. Governments can help distribute standardized user specifications and contracts, which elaborate on the work of M&V^[59]. Standardized contracts and measurement and verification processes are also encouraged to help stakeholders understand EPC comprehensively.

(3) Removing institutional barriers

ESCOs and private sectors have limited access to essential information on the EPC project, such as energy efficiency measures and finance, energy efficiency/projects database, and special efforts. The information is vital for ESCOs and private sectors to get involved in energy efficiency constructions^[63]. The government must establish an information system and database that is transparent to the private sector. To overcome the institutional barriers, the government can provide the best practices, guidelines, and demonstration projects^[55,63]. For instance, Korea has issued a law allowing the Korean public sector to help companies understand the ESCO business by publicizing the demonstration project. Thus, as a demonstration project applied by this new law, the first ESCO project for replacing a conventional lighting system in the public sector was carried out in the Kwachon government complex, and soon after this demonstration project, public and private sectors showed their interests in the ESCO market and the diversification of project types^[55].

Having transparent and equitable pricing policies is essential in areas where energy prices are distorted. Additionally, ensuring that people cover the actual economic costs of electricity through proper metering and reliable billing systems is equally important^[63]. Clients may have little awareness of building energy performance issues, meaning relevant programs regarding public understanding of energy conservation should be implemented. Programs like seminars, websites, videos, workshops, case studies, brochures, and other publications serve to share knowledge about energy-efficient technologies, products, and equipment. They also highlight opportunities for energy savings, provide insights into current and projected energy costs, and promote awareness of energy efficiency standards^[19]. Additionally, a standardized document was helping users negotiate and make authorities release energy performance contracts for ESCOs. Information and training programs should be designed to reach the general public and critical stakeholders, including procurement-focused banks, energy efficiency engineers, energy managers, manufacturers and suppliers of lighting and equipment, leasing companies, and energy auditing firms.

6.2 Further development of ESCO

The excellent performance of contract design makes ESCOs competitive for market expansion. Also, it is necessary to establish a database for contracts and implement procedures that can be made available to ESCOs. ESCO's association can take this role and disseminate information regarding contracts. Sometimes, ESCOs can benefit significantly from international interactions, such as

advanced technology, external EPC management experience, and substantial international resources^[12,63].

(1) Project development plan

Suitable planning and objective control are equally essential for organizations involved in projects. Generally, for the project development plan, certain necessary activities must be considered: initial project scoping, evaluation of ESCOs, execution contract for an energy audit, evaluation of facility and development of project scope, the illustration of technical details of project implementation, and secure financing. The framework, goals, and control mechanisms are essential for project organizations, significantly determining the project quality^[44].

(2) Related financial approaches

Conducting and preparing the feasibility study for funding is of importance. The financial analysis is the basis for an owner and an ESCO to improve their security ability, which helps them obtain more practical financial information and control uncertainty risks. Indeed, debt and equity financing sources must be located^[12,19]. In addition, implementing an energy audit can provide fair chances for energy savings. Also, it can enhance the owner's awareness to structure the effective energy consumption pattern, reduce energy consumption, and maintain or even improve occupant's comfort and health. An energy audit may identify and prioritize energy consumption. Particularly for a commercial building, its HVAC, lighting, and production equipment are usually the primary focus of energy audit because they consume the most energy. Thus, an energy audit's scope and level of detail can significantly impact costs. Defining a clear scope and specific information before conducting the audit helps focus efforts on feasible projects, thereby managing expenses effectively^[21].

(3) Ongoing measurement and verification

Continuous M&V activities are cost-consuming for an operational project. Ongoing M&V activities can benefit the project in many ways. They can analyze energy conservation degrees, control operation performance, verify proper O&M, and identify cost-saving performance guarantees. Based on M&V activities, all parties could find the appropriate way to allocate and balance risks^[44,55].

(4) EPC simulation and assessment technique

ESCOs can develop various methods to simulate and assess the contracting process before and during construction. One logistic model could predict the potential disputes during contract implementation, which reminds the client and the ESCO to develop a good relationship. In addition, contract duration is essential when the legal period is too long, losing bidding competitiveness too short and incurring significant loan risks^[46]. Also, implementing the necessary techniques to simulate the whole building life-cycle process, which influences energy performance and environmental sustainability, is essential before the project's commencement. Considering uncertainty, building performance simulation, and cost-benefit analysis are valuable for practitioners in obtaining important building information. The further development of ESCOs requires techniques more oriented to construction and appropriate flexibility.

(5) Risk management

By adopting specific risk control and management techniques, ESCOs can analyze the probability distribution of energy-saving fluctuations using mathematical methods. Various parameters fluctuations could be considered, such as weather conditions, occupancy, operating hours, and thermostat set-point during the contract period^[45,55,69]. Through continuous risk assessment and control, ESCOs can modify the deviations between the actual work and the expected outcomes and decrease the risks jeopardizing the projects to the minimum extent, ultimately improving the ESCOs' competitiveness.

(6) Trust building and reputation

The success of the contract is determined by the alliance relationship between an owner and a contractor and the high-quality collaboration of team members^[36]. The alliance relationship should be maintained seriously during the project periods to finish the project well. Such dedication to mutual trust is crucial in fostering a solid willingness to cooperate, particularly when facing adversarial challenges^[36].

Additionally, company reputation can be considered essential information when evaluating a company's total performance, such as background, service level, and achievements. Company reputation enables ESCOs to quickly establish confidence in mind, even without substantive contact with customers^[57]. Corporate reputation can be regarded as an essential reference while previous collaboration experience is absent. Based on the lack of interaction or transaction history, reputations are important for involved parties to decide whether they should trust others^[44].

(7) Data-driven EPC development

The rapid development of computer science makes it possible to conduct building operations and reduce energy consumption. For example, blockchain technologies allow stakeholders to share information and prevent information modifications. Various intelligent algorithms, e.g., deep learning, are used to predict building hourly energy consumption^[10], anomaly detection^[7] and control-oriented

performance optimization^[6]. Additionally, various innovative technologies should be applied under the climate and society development framework in the context of climate change.

6.3 Strategies for owners

(1) Awareness and perception of EPC benefits

Low awareness and scepticism are considered the essential factors limiting the development of EPC projects^[44,59]. The survey highlighted the role of disseminating information in promoting EPC, especially when financial and technical conditions are insufficient. The interactions will receive credits from users regarding EPC promotion^[59,70].

(2) Selection of ESCOs

Considering the selection of ESCOs, the owner should consider many factors for the project’s success. The essential principles for the owner to select ESCOs usually should consider their energy audit capacity, a clear project development plan, an accurate M&V strategy, overall competitiveness, established credentials, and previous reputation^[15,41,47,57,64,66].

(3) Performance, measurement, and verification (PMV)

As for the lack of standardized conditions in implementing EPC contracting and PMV savings, there may be a certain level of mistrust. For the financial parties (owner or financial institutions) specified in the contract, a lack of standards can dampen their enthusiasm to promote EPC^[19,44]. Standardizing the contracting process and PMV can help end-users and financial institutions better understand EPC, fostering quicker adoption. Additionally, standardized contracts and PMV can reduce transaction costs^[59].

(4) Strategies and success factors for EPC

As shown in [Figure 3](#), the government, owner, ESCO, and third-party financier are the four key roles in the EPC. From what has been discussed in section six and the table, a diagram ([Figure 6](#)) is developed to directly understand the relation among the stakeholders, diffusion strategies, and influencing factors. Each influencing factor for adopting EPC is matched with relevant interested parties and their strategies. The right column in [Figure 6](#) shows the matching numbers of influencing factors corresponding to those in [Table 2](#). Making one particular strategy should have further thought of other influencing factors. For instance, if the government wants to make an excellent economic and financial incentive program, it should consider several influencing factors, such as the finance and taxation policies, economic environment, energy price stability, and available funding channels.

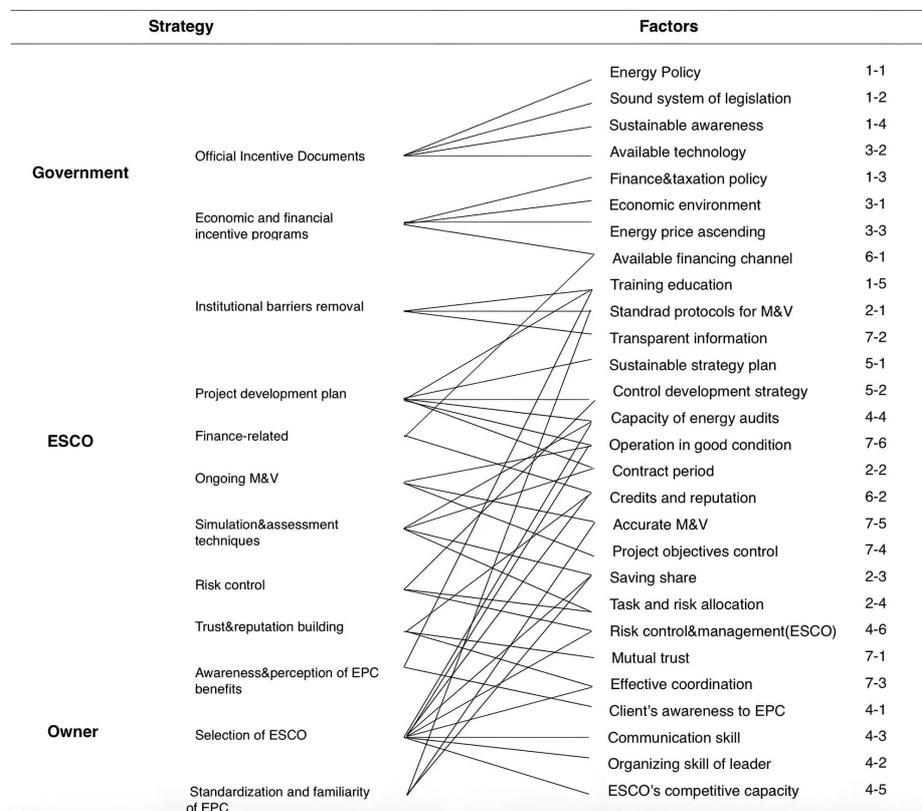


Figure 6. A summary of stakeholders’ strategies and factors influencing EPC. EPC: energy performance contract; ESCO: energy service companie.

Based on the analysis of EPC adoption strategies from different viewpoints above, **Table 3** categorizes those strategies into five groups: political (P), Economic (E), Organizational (O), relational (R), and Technical (T). Each group has several sub-items for a detailed explanation. For instance, the P group has sub-items P1 and P2. In the table, the relationship between the involved parties is presented in the column *Parties Involved*, which helps readers clearly understand the obligations and rights of each party when executing those strategies. In **Table 3**, the relationships among government, owner, ESCO, and EPC adoption have been sketched, and the plan for them to adopt EPC has been summarized, as shown in **Figure 7**. For instance, to promote EPC adoption, the strategies for an owner should stress E1, E3, R1, T1, T2, T5, O2, and O3. The specific content for the sub-item can be found in **Table 3**. In addition, an owner should also attach importance to the influence of government and ESCO.

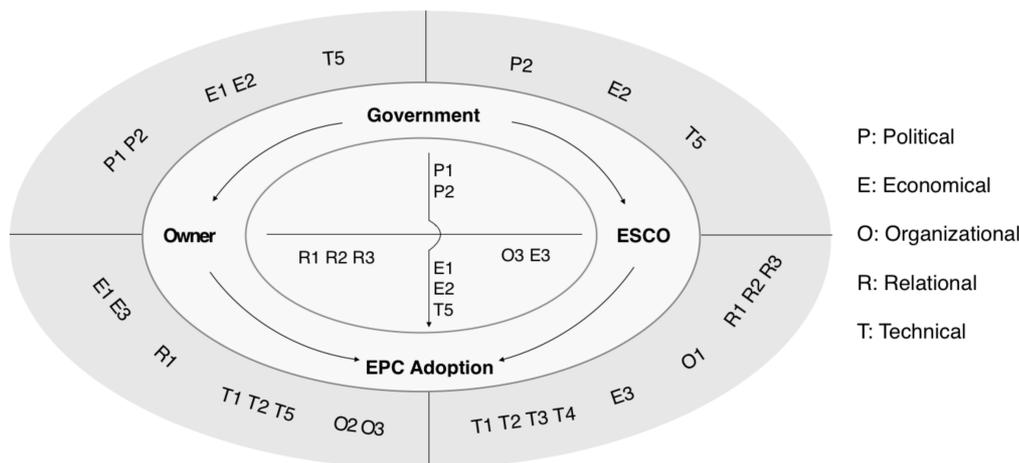


Figure 7. Relationships among parties with their corresponding strategies. EPC: energy performance contract.

Table 3. A summary of EPC adoption strategies.

Action	Category & Code	Description	Parties Involved	Reference
1. Official incentive documents and programs	Political P1	Amend the existing provisions of government procurement for energy efficiency projects.	Government → Owner/EPC	[19,46,55,63]
	Political P2	Establish programs to encourage companies to execute energy saving and efficiency.	Government → Owner/ESCO/EPC	[55]
2. Economic and financial incentives	Economical E1	Promote economic incentive policies, guidelines, and demonstration projects to regulate the energy efficiency market.	Government → Owner/EPC	[45,55,63]
	Economical E2	Provide preferential policies such as low-cost loans and special purpose funds to involved parties.	Government → Owner/ESCO/EPC	[55]
	Economical E3	Locate the exact sources of debt and equity financing and structure	Owner/ESCO → EPC	[12,19]
3. Organization & Management	Organizational	Identify the project organization	ESCO	[21,41]

	O1	structure, project objectives, and control mechanism to make a fully well-planned development plan.	→ EPC	
	Organizational O2	Implement energy-efficiency projects through EPC with limited financial or technical capabilities and build confidence in EPC.	Owner → EPC	[44,59,70]
	Organizational O3	Choose an ESCO that considers energy audit capacity, a clear project development plan, an accurate M&V strategy, overall competitiveness, organizing skills, credits, and previous reputation.	Owner → ESCO	[16,41,47,57,64]
4. Work relationship	Relational R1	Establishing an alliance relationship, trust between an owner and a contractor, and good coordination within a team contribute to a strong desire for cooperation, especially in adversarial problems.	ESCO/Owner → EPC	[36]
	Relational R2	Build a positive corporate reputation to achieve clients' trust without a substantive contact.	ESCO/Owner → EPC	[41,57]
	Relational R3	Develop an accurate prediction of energy saving and ergonomics considering fluctuating factors: weather conditions, occupancy, operating hours, and thermostat set-point during the contract period.	Owner/ESCO → EPC	[45,55,69]
5. Technical assessment & management	Technical T1	Conduct ongoing M&V activities to quantify energy savings from a project, monitor equipment performance, verify proper O&M, and identify cost savings performance guarantee(s).	Owner/ESCO → EPC	[41,59,55]
	Technical T2	A Scientific method to estimate the suitable contract period.	Owner/ESCO → EPC	[46]
	Technical T3	Simulate the whole building life-cycle process, which influences energy performance and	ESCO → EPC	[65]

		environmental sustainability before the project commencement.		
Technical T4		Conduct an uncertainty analysis combining building performance simulation and cost-benefit analysis.	ESCO → EPC	[45,55,69,71]
Technical T5		Standardize the contracting process and PMV to help end-users and financial institutions better understand and easily adopt EPC.	Government/Owner → EPC Government → ESCO	[61]

EPC: energy performance contract; ESCO: energy service company; O&M: operations and maintenance; M&V: measurement and verification.

7. Conclusions

This paper summarizes the existing literature on energy performance contracting and identifies various critical issues of EPC. Seven categories of challenges are elaborated to illustrate the current development of EPC; 28 essential factors of success for EPC adoption are proposed to shed light on how to take measures to overcome those barriers and enable the successful adoption of EPC. Finally, focusing on the issues and factors above, EPC diffusion strategies are proposed, and the cross diagram indicates the links between the strategy and the critical success factors. The authors also categorize the strategies based on their relevance to political, economic, organizational, relational, and technical aspects, which are ultimately incorporated into the stakeholder diagram in an EPC project.

Based on the research review, the government's role in promoting EPC is vital for providing preferential policies to the developing ESCOs and publishing the relevant guidebooks and legislation to overcome the current barriers to EPC development: official incentive documents, incentive policies, and institutional barriers. In addition, ESCOs' capabilities of designing contracts, maintenance and verification, and accurate simulation and assessment techniques are the keys to EPC market expansion. Standardizing EPC contracting and performance measurement and verification can greatly assist building owners in embracing EPC. Future research by the authors will further explore the relationships among government, owners, ESCOs, and third-party financiers by quantitative research methods.

Declarations

Authors contribution

Yang E: Investigation, writing-original draft.

Chen C: Writing-original draft.

Li K: Conceptualization, analysis.

Guo K: Conceptualization.

Hua Y: Supervision.

Zhang L: Conceptualization, supervision, review-original draft .

All authors approved the final version of the manuscript.

Conflicts of interest

Limao Zhang is the Editor-in-Chief of *Journal of Building Design and Environment* . Other authors declared that there are no conflicts of interest.

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