Heliyon 10 (2024) e30135

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Managing energy consumption by adapted energy performance contracting modes in rural China

Mingshun Zhang [a,*], Ruoxin Li [a], Chun Xia-Bauer [b]

[a] School of Environment and Energy Engineering, Beijing University of Civil Engineering and Architecture, No.1, Zhanlanguan Road, Beijing, 100044, China

[b] Wuppertal Institute for Climate, Environment and Energy, Döppersberg 19, 42103, Wuppertal, Germany

A R T I C L E I N F O

Keywords:
Energy performance contracting
Energy service companies
Rural houses in China
Survey in China
Rural energy policy in China

A B S T R A C T

Energy performance contracting (EPC) as a market instrument has been effective in promoting energy efficiency worldwide, but it has encountered many insurmountable obstacles in rural energy management. In this study, based on the characteristics of energy management in rural areas, three EPC modes are designed and tested in 24,000 rural households. The test results show that two adapted EPC modes of local government involvement and energy payment directly from the national grid can effectively overcome the barriers encountered in the traditional EPC modes and work well under the economic and social environmental conditions in rural areas. The key to the adaptation of the traditional EPC modes is the introduction of the local government as the third party. Participation of the third party can effectively reduce and remove the barriers and risks and increase the mutual trust between the clients (households) and the energy service companies (ESCOs). Based on the testing results, this study suggests that governmental departments should formulate relevant EPC policies and technical guidelines within the rural context. This research recommends that farmers should not manage their energy services by themselves and it is suggested to out-contracting ESCOs by applying the modes developed and tested by this paper.

1. Introduction

Energy Performance Contracting (EPC) is a market-based energy saving mechanism introduced to China in 1996, which was started in Western countries after the world oil crisis in the 1970s [1]. EPC is a type of contractual arrangement between clients and energy service companies (ESCO), in which the ESCO provides a complete set of systematic services, and recovers the investment and profit from the energy-saving benefits obtained by the client after the energy-saving renovation according to the contract, which can be seen that this mode largely transfers the energy-saving risks of the owner to the energy-saving service company [2–4]. ESCO is a specialized company that provides services such as energy use diagnosis, energy saving project design, financing, renovation (construction, equipment installation, commissioning), and operation management [5].

China's EPC, started in 1996, was motived by the purported superior efficiency of energy service companies, the advantage of energy efficiency service provision unhindered by cumbersome government bureaucracy and access to private finance. At an earlier stage, China's EPC was adopted by the sectors of energy-intensive industries (e.g. power generation, cement industry, energy-intensive

* Corresponding author.
E-mail address: zhangmingshun@bucea.edu.cn (M. Zhang).

https://doi.org/10.1016/j.heliyon.2024.e30135
Received 28 November 2023; Received in revised form 20 March 2024; Accepted 20 April 2024
Available online 22 April 2024
2405-8440/

manufacturing industries). Then EPC was applied in building sector, due to China's large scale of buildings and great potential for energy savings in the building sector [6]. EPC is mainly driven by China's building energy efficiency policies on low-carbon development, resource efficiency and pollution reduction. Chinese government unveils an ambitious plan for climate mitigation and aims to achieve carbon neutrality before 2060. While significant efforts have been made in urban China, energy consumption in rural area has received little attention. However, rural houses account for one-third of China's total building stock and for more than 20 % of building operational energy consumption [7]. Heating and cooking consume the most energy in rural houses. Most rural houses are built by local construction workers and are not energy efficient. Coal and unprocessed biomass are the major source of conventional heating and cooking. In addition, rural households generally lack energy efficiency awareness. Such a combination makes rural energy consumption particularly carbon-intensive. Besides, indoor cold due to bad building insulation and indoor air pollution resulting from burning coal and unprocessed biomass have imposed adverse impacts on rural households' health. Thus, sustainable energy consumption in rural China is vital for decarbonization and sustainable development in China. In fact, building envelope energy retrofitting and sustainable heating and cooking technologies are available on the market and have already been piloted in rural China. Scaling up pilot has encountered various barriers, ranging from lack of awareness among rural households, high costs and limited access to financing, missing business models, not well-developed supply chain of related products, to inadequate policy framework [8].

Farmers have limited financial means to retrofit their homes. Farmers can improve the comfort, convenience, and safety of their homes through energy efficiency improvements and clean heating. However, farmers are limited in their ability to afford the investment and operating costs of energy efficiency and clean heating. High reliance on government subsidies. Currently, financial subsidies are the main driving force behind energy efficiency retrofits and clean heating in farm buildings [9]. On the one hand, the central government's financial support policy plays a fundamental role in promoting the development of clean heating and energy efficiency in rural areas. Even though finance plays an important role, it is difficult to achieve clean heating and energy efficiency in rural areas in the long term if relying on financial resources alone. China favours EPC when moving from the existing governmental subsidy-oriented rural energy efficiency policy to a business-oriented policy. Feasible and functional business models are crucial for achieving high energy efficiency and low-carbon energy consumption in rural China.

There are many EPC modes worldwide and commonly used are the shared energy savings model, guaranteed savings mode and energy-cost trust mode (which is also called contract energy management, energy outsourcing or energy supply contracting) [10,11]. There are various barriers reported in international EPC experiments that include market, finance and institutional barriers, poor energy pricing policies, high transaction costs, and many risks related to EPC project design, facility, construction, operating, revenue, financial force majeure and insurance have prevented upscaling of EPC [12–15]. There are very few studies concerning EPC experiences in rural energy consumption and Huimin [16] has concluded that there are more challenges and barriers arise from rural EPC projects, given the facts of limited financial capacity and low energy awareness of farmers, small-scale energy efficiency projects (many energy-efficiency projects and ventures in rural areas are too small to attract the attention of both ESCOs and financial institutions), relatively high operational costs of rural EPC projects (villages are far from others and thus ESCOs need more travel costs for operating and maintaining the facilities) and thus traditional EPC models that have been widely applied in urban EPC projects need to be adapted and tailor-made to local conditions. Wide peer-reviewed studies point out that key factors for designing a useful and well-functioning EPC model are how to allocate both risks and profits between ESCOs and clients, the provision of finance, and the repayment mechanisms of ESCOs [17–19].

Literatures point out that traditional EPC models that come of urban and industrial energy services are not applicable for rural energy services [20,21]. Recent studies have experienced many solutions to overcome barriers and increase possibilities of making EPC models functioning in rural contexts. Those experienced solutions include increasing governmental subsidies, mobilizing green financing, increasing farmer's awareness on energy efficiency and some studies have even tested the increasing of energy price [22,23]. The expected outputs of those solutions are not realized [24], and the rural energy service market is looking for new solutions [25]. Novelty of this study is to explore new EPC models adapted from the traditional models within rural context and the new models are able to overcome barriers arise from traditional models, to mobilize participations of stakeholders related to EPC models and to improve rural energy services towards low-carbon and sustainability.

Current efforts on energy development in rural China towards clean energy system are focusing on making electricity and gas accessible to all and phasing out traditional raw coal-burning [26]. Main countermeasures are building rural energy infrastructure and providing governmental subsidies to farmers [27]. Both national and local governments play vital role in planning and implementing the countermeasures, while private sectors are hardly involved and participations of farmers and relevant stakeholders are not efficiently mobilized. The recent practices show that those efforts do not achieve the initial goals, given to the facts that those countermeasures are high-investment oriented and governmental subsidy-based policies are not always guaranteed when economic conditions are not prepared and local governmental debt is high [28]. As the result, many rural areas have to give up using those relatively expensive electricity and natural gas and revert to use coal and traditional straw and firewood [29]. The great challenge facing China's rural clean and low-carbon energy consumption is how to ensure that the existing countermeasures could be sustainable by moving from high investment and governmental subsidy based non-market mechanism towards rural condition oriented and market-based mechanism [30]. Novelty of this study is also to explore the way how the market-based EPC models could be functioning in rural areas by mobilizing involvements of private sector and fostering communication and cooperation among stakeholders of farmers, business, local governments and energy service providers. Partnerships of new energy enterprise-village collective linkages should play a key role in the new EPC model that will be specifically addressed by this study.

The definitions of farmers and households are used synonymously in this study. Households in this study means farmer's households. The average size per household is about 3.7 persons/farmers.

Building on literature study and analyses of the existing limited rural EPC projects, this paper addresses key issues of why the traditional EPC modes are not working and how the traditional EPC modes could be adapted to rural contexts. This paper builds on a case study. In this case, three EPC modes have been designed, based on existing EPC experiences in rural China and then these three models have been tested in about 24000 rural households from about 260 villages in the provinces of Henan and Gansu, China. It aims to explore the possibilities that adapted EPC modes are well-functioning and can be a useful and successful policy approach for achieving sustainable and low-carbon energy consumption in rural China. Specifically this paper addresses the following issues.

1) Why are the traditional EPC modes not well-functioning in rural EPC projects and what are the key failure factors when applying the traditional EPC modes? This question is to debate the conclusions drawn in kinds of literature that the EPC modes do not work well for rural applications.
2) What are the key successful factors that need to be considered in designing useful and functioning EPC modes? A good answer to this question is conducive to designing a suitable EPC mode for rural areas。
3) How is an adapted EPC mode functioning in rural EPC projects? This question is related to the testing of the EPC modes to be designed by this research and the answer to this question will generate good suggestions for applying EPC modes in rural areas
4) What are the policy implications for upscaling EPC projects in rural areas?

2. Research and data methodology

This is an empirical research that is part of the EU Switch Asia project, entitled Promoting sustainable residential energy consumption in rural China. The target groups of this research are therefore selected by this EU project. This research is structured as the following Fig. 1.

Wide-scale peer-reviewed studies investigating the development and up-to-date status of EPC practices in rural energy management are scarce [31]. For getting insights into China's EPC projects in rural energy management, pre-coded questionnaire surveys have been conducted among the ongoing rural EPC projects and the surveys aim at defining the profile of rural EPC projects and identifying both successful and failure factors among the existing rural EPC projects. Due to the limited number of ongoing rural EPC projects, the status assessment focuses on interviewing EPC stakeholders of farmers/households, villages, local governments, and ESCOs that are involved in the rural EPC projects. In total, the questionnaires have been distributed to 6 ongoing rural EPC projects and a number of 116 households, 67 villages, 38 local governments, and 25 ESCOs have been interviewed in the 2nd half of 2019. Questions included in the pre-coded questionnaire are defined by taking into account the findings of literature study and the researcher's experiences in managing similar EPC projects. The questions included in the questionaries focus on driving forces, constraints, current performance of contracts, modes being adopted, main solutions being taken, types of contracts, services and project investment, payback times, and

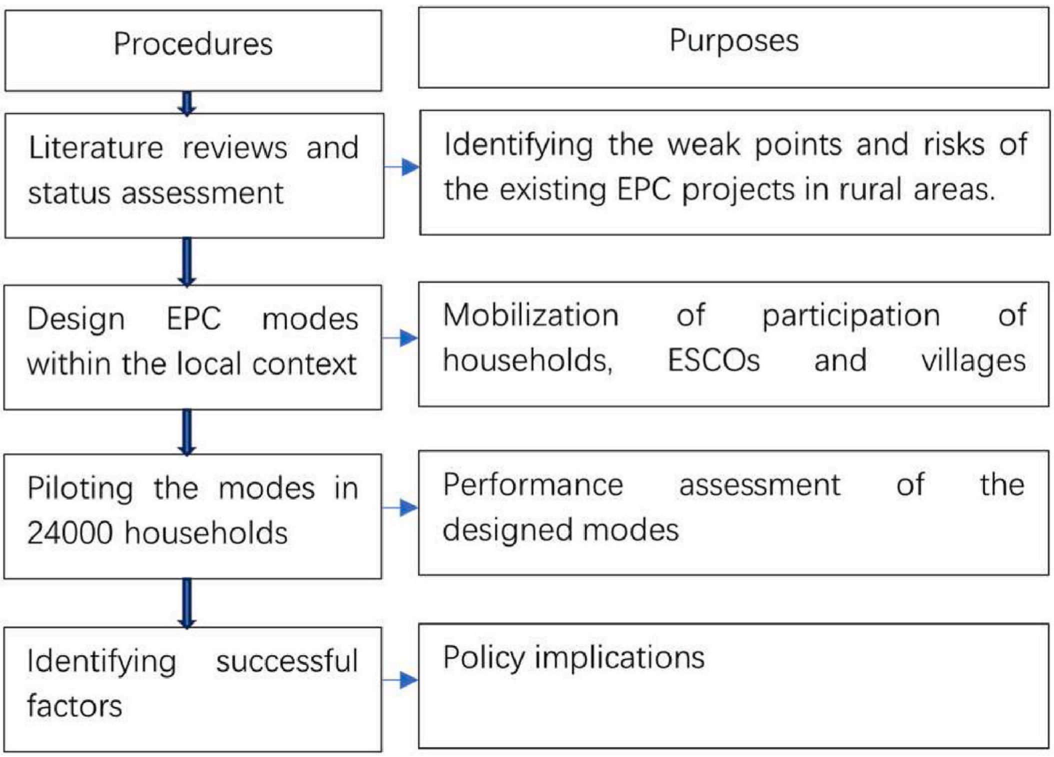

Fig. 1. The research structure.

operation and maintenance, savings, and policy framing. Interviews focus on discussions with the stakeholders on the questions related to the performance of contracts, conflicts and disputes, payment issues, cooperation between ESCOs, and households and improvement of energy efficiency contributed by the EPC projects. The surveys will result in identification of the key barriers to rural EPC development.

Building on the mentioned-above literature study and status assessment, three EPC modes are designed within the local context. Local stakeholders are intensively involved in the mode-designing process. In particular, farmers/households and ESCOs have expressed their wishes and worries in proposing the modes. Farmers expect that the EPC project should improve their room comfort and indoor air quality while energy costs will not increase. ESCOs look for EPC projects that are characterized by low risks, high profit, short payback time and low investment. Villages and local governments are highly motivated, given to the national and local policies for fostering and upscaling cleaner heating and sustainable low-carbon energy consumption in rural areas. Balancing the different interests of different stakeholders, we designed one of the three EPC modes, in which local governments are also involved as the third party for supervising and supporting the cooperation between households (party A) and ESCOs (party B).

For piloting the designed three EPC modes, the challenge is to mobilize participation of both farmers/households and ESCOs. Awareness-raising campaigns among rural households are conducted by the local authorities with significant support from the village committees. The campaigns aim at, on one hand, improving farmers' awareness of sustainable low-carbon energy consumption, and, on the other hand, informing farmers that new rural low-carbon energy policies are being developed and will come into force in the coming years. The new rural low-carbon polices may include forbidding coal-burning and burning unprocessed biomass, promoting the use of renewable and clean energies, publishing the energy efficiency act of rural houses and indoor air quality control. Through the awareness-raising campaigns, about 24000 households from the provinces of Henan and Gansu were selected, based on three criteria: households' willingness to participate in the pilots; b) householders' willingness and financial capability to partly cover the upfront and maintenance costs, and; c) recommendations from local village committees. ESCOs have also expressed their interest in providing energy services, including investments, while local authorities will provide both policy and financial (subsidy) support. When necessary, local authorities can be directly involved in the EPC modes.

Testing the designed three modes aims to assess the performances of modes and to monitor whether the key barriers identified by this research are not reduced or removed. Key barriers are identified from a set of 6 specifications and 26 checking points that are developed, based on literature reviews and status assessment. The specifications are related to the overall performance of the EPC modes, successful factors, weak points, risks, and results in achieving sustainable low-carbon energy consumption and sustainability (whether the EPC modes could be disseminated). All checking points are answered separately by households and ESCOs. Each checking point was scored on a scale of 0–10. A high score means a more serious barrier and a low score means less barrier. The EPC contracts under this research were signed at the end of 2020, and, after two-year implementation, the testing (performance assessment) was conducted in March–April 2023. In this research, a total of 24000 households and 25 ESCOs are involved. Among the 24000 households, 21230 households have responded to the checking points with a response rate of 88.5 %. All 25 ESCOs have responded to the checking points. For taking an in-depth look into the comments of the households, ESCOs, villages and local authorities, sampling in-site visits were conducted in March 2023.

This research used different methods to ensure that data gathering and analysis deliver evidence-based qualitative and quantitative information, based on diverse sources. The use of different data and sources, and methods to gather data aimed to ensure triangulation to validate facts.

The approach applied the following 3 different data-gathering methods that complement each other. Desk reviews provide a good understanding and assessment of the ongoing EPC projects, direct interviews are helpful for getting practical insights of the attitudes of different stakeholders and surveys provide concrete data on various aspects of EPC performance.

1) Desk review of the pilot documents, particularly EPC contracts and relevant evaluation reports on the pilot projects.
2) Interviews with different groups of stakeholders
3) Survey amongst specific stakeholders (partners, associate partners, target groups). The survey aims to get insight into how the project stakeholders themselves fell with the EPC pilot project. Are they satisfied with the project design, implementations, management and coordination, efficiency and effectiveness, and impact and sustainability.

For data quality control, an academic committee has been established. This committee has reviewed all the questionnaire, all answers given by the households and ESCOs, and the statistics of the surveyed data.

There is a caveat to this study. All EPC project contracts were signed at the end of 2020 and all the projects have been implemented in two years, which is shorter than the contracted period of 7–10 years. As there are no contracts completed, it may be earlier to make conclusions about the EPC modes.

3. Results

The results achieved by this study demonstrate the current situation of EPC in rural energy services, and, based on which, it reveals the opportunities and challenges encountered in the current promotion of EPC in rural energy services. Especially this study has answered the fundamental question why the traditional EPC model does not work in rural energy services. Based on the findings, three EPC models for rural energy services are developed and the developed three models intended to remove the barriers encountered when applying the traditional EPC models. Thereafter, the results have provided detailed insights of testing of these three EPC models. The details are described in the following part of this chapter.

3.1. Profile of EPC in rural energy services

The survey data on the 249 samples provides information on the size of ESCOs, type of EPC, investment size, the contract period, main solutions for improving energy efficiency conducted by ESCOs, and (expected) average pay-back time. Table 1 presents the main features of the existing EPC projects in the rural energy services in China.

Table 1 shows the main type of EPC project is the energy-cost trust mode, which is significantly different from the EPC mode of shared energy savings [32] that is commonly applied in urban energy services. The reason that the commonly used shared energy savings mode is not applied in rural China is the difficulty in defining the baseline of energy consumption in rural energy management. Defining the baseline of energy consumption is one of the key factors being taken into the EPC contract. In rural areas, however, it is almost impossible to define the baseline, due to lack of energy consumption data. EPC contract in energy-cost trust mode is based on agreed energy prices between clients and ESCOs. Thus baseline data is not required in energy-cost trust mode. Table 1 presents the following main features of EPC projects in rural China.

1) ESCOs involved are small-sized with staff below 50. In urban EPC projects, there are many medium-sized and large ESCOs involved.
2) Contract period of 7–10 years, which is relatively longer than the EPC projects in urban areas [33].
3) Investment per EPC project is about below 11000 Chinese Yuan (e.q. 1570 USD), which is significantly lower than the investment of urban EPC projects.
4) The main solutions are the adoptions of photovoltaic panel and heat pump. There are very few EPC projects that are adopting gas and electricity. Photovoltaic panel and heat pump are good for low-carbon energy consumption as well as for cleaning rural environments.
5) Payback time is between less than 4 years and 6 years. Payback time is a crucial factor for assessing the performance of EPC modes. Zhang [34], by a nationwide EPC survey, concluded that the average pay-back time is 2.8 years, with a minimum value of 1.8 years and a maximum of 4.4 years for industrial and urban EPC projects. It is obvious that payback time in rural EPC projects is about two times of the industrial and urban EPC projects and this can explain why the traditional EPC modes are not functioning in rural energy management. In most cases, this survey found that payback time is often half of the duration of the contract.

3.2. Main opportunities and challenges in adopting traditional EPC mode in rural energy services

To identify the main opportunities and challenges in adopting traditional EPC modes in rural energy services, all 249 respondents and interviewees are invited to give a score of 0–10 for the factors listed in Table 2. A low score means less important and high score means more important. Scores obtained from all 249 respondents were subsequently added. This gave an aggregate score for each of the factors with a range of 0 (less important) to 10 (most important).

EPC as a market instrument is mainly market-driven in many countries. It is, however, different in China, in which EPC is largely policy-driven [35]. As presented in Table 2, the great opportunity for adopting EPC in rural energy service has been also the sound policies. Those policies are related to low-carbon; environmentally friendly, health, poverty reduction as well as rural sustainable

Table 1
Profile of EPC projects in rural China, N = 249.

Factors	Features	Numbers	In %
Type of EPC	1. shared energy savings	0	0
	2. guaranteed savings	20	8.0 %
	3. energy-cost trust mode	229	92.0 %
Size of ESCOs involved	1. ESCO has less than 20 staff	112	45.0 %
	2. ESCO has staff 21-50	114	46.0 %
	3. ESCO more than 51 staff	23	9.0 %
Contract period	1. 7 years	117	47.0 %
	2. 10 years	119	48.0 %
	3. 15 years	13	5.0 %
Investment per EPC	1. Less than 5000 Chinese yuan	32	12.9 %
	2. 5001–8000 Chinese yuan	48	19.3 %
	3. 8001–11000 Chinese yuan	138	55.4 %
	4. 11001–14000 Chinese yuan	31	12.4 %
	5. 14001–20000 Chinese yuan	0	0 %
Main solution/technology	1. photovoltaic panel	118	47.4 %
	2. heat pump	107	43.0 %
	3. Gas	11	4.4 %
	4. Electricity	13	5.2 %
Pay-back time	1. Less than 4 years	48	19.4 %
	2. 4 years	77	30.9 %
	3. 5 years	87	34.9 %
	4. 6 years	26	10.4 %
	5. 7 years	11	4.4 %
	6. 8 years	0	0 %

Source: Primary data 2020

Table 2
Opportunities and challenges in adopting traditional EPC mode in rural energy services, N = 249.

	Factors	Average score
Opportunities	● Strong policy support	9.5
	● Financial support (subsidy)	9.0
	● Enough space for installation of facilities (PV, heat pump)	8.5
	● Rich in sustainable energy sources (solar, geothermic)	7.6
	● Great potential for energy savings	7.5
Challenges	● Limited financial capacity of farmers	9.2
	● Low awareness of energy efficiency	9.0
	● Low interests in adopting sustainable energy	8.7
	● Low population density, long distances between villages, and thus relatively high maintenance & operational costs	8.1
	● Small-size project, low profits on energy savings	6.8

Source: Primary data 2020

development, which are on the top agenda of both national and local governments. Both national and local governments have also established various rural subsidy programs and those subsidies are available for fostering and enlarging rural EPC markets. Opportunities for promoting rural EPC development also include easy access to renewable energy such as PV and heat pumps and quite enough space for installations of PV panels and heat pumps. Last, but not least, as compared to energy consumption in urban areas, energy efficiency in rural areas is much lower and there is great potential for energy savings to be mobilized in rural energy consumption.

There are many studies investigating the challenges of EPC projects [36–38]. Wang [39] discussed the five critical challenges that exist in executing EPC projects, and they also proposed some lessons and implications for achieving better performance in EPC projects. In general, the challenges of EPC projects are different from country to country and are very much dependent on local conditions. Usually, challenges exist in the whole process of EPC projects, such as feasibility study, design of contract, operations and maintenance, monitoring, payments, responsibilities and risks, financing and insurance [40,41]. In addition to the common challenges in EPC projects, different challenges have been identified in rural EPC projects in China. Those specific challenges are presented in Table 2. The most serious challenges are the limited financial capacity of rural households and the low awareness of energy efficiency. Farmers are used to burning unprocessed biomass and raw coal which are very cheap, as compared to the energy services to be provided by the ESCOs. Another specific challenge is the low population density and long distances between villages that lead to relatively high maintenance & operational costs.

By this research, we conclude that EPC would be well-functional in rural energy services in China if the city-based EPC modes are adopted for rural conditions and feasible modes are developed.

Table 3
Barriers to adopt traditional EPC modes in rural China, N = 249.

Specifications	Checking points	Average score
Contracting	1) Lack of trust between rural households and ESCOs	9.6
	2) Poor quality of rural houses that do not meet the criteria of installations of facilities.	8.3
	3) Lack of knowledge and experience in EPC projects	7.2
	4) Low willingness to adopt the EPC mode.	8.2
	5) Contracts are not clearly defined and not in enough details	8.3
	6) Types of force majeure are not specified.	4.5
	7) Lack of clarity on the actions of households and ESCOs in the event of force majeure g.	5.3
	8) Lack of clarity on the responsibilities of the households and ESCOs in the event of force majeure.	4.8
	9) Failure to specify and verify conditions for termination of contracts.	5.8
	10) Actions for both household and ESCO are not included if the contract is terminated during the contract period.	5.2
Feasibility study and design	11) Design flaws in the selection of technologies and solutions.	3.8
	12) Solutions to achieve goals are not feasible	2.9
	13) Feasibility studies are not well conducted, e.g., climate change is not included.	5.1
Facilities and construction	14) Facilities are not feasible.	4.2
	15) The costs of facilities are too high.	7.5
	16) Facilities are too complex for operators.	7.7
Operation and maintenance	17) Cost overrun	6.4
	18) Relatively high operational costs	8.2
	19) Delay in completion	3.7
	20) Failure of works to meet performance standards at the time of completion	6.2
Revenue and financing	21) Lack of financing	8.3
	22) Difficult to have payments directly from household	9.6
	23) Minimum saving is not realized.	3.7
	24) Change in tariff (e.g. price of electricity).	6.5
	25) Delay in payment.	8.6
	26) Unforeseen increase in staff salaries	6.7

Source: Primary data 2020

3.3. Why the traditional EPC modes are not working in rural energy services

Both literature reviews and our interviews show that the existing EPC projects in rural China are not well-functioning and it is extremely difficult to promote and upscale EPC projects in rural energy services [42,43]. To identify the reasons that the traditional EPC modes are not working in rural China, a set of 6 specifications and 26 checking points presented in Table 3 have been developed, based on literature studies, interviews conducted in this research, and our experiences in adopting EPC in urban energy services.

Table 3 presents that there are 8 checking points, in which each point has an average score above 8.0. These 8 checking points are identified as the key reasons that the traditional EPC modes are not well-functioning in rural energy service in China. During the interviews, we have discussed the scoring rules with the stakeholders and the scoring rules are recognized by stakeholders. Taking an in-depth look at the 8 points, the most serious two barriers (checking point has a score above 9.0) are as below.

1) Lack of trust between rural households and ESCOs. Many researches have revealed barriers encountered in EPC projects and an important barrier is the lack of well-established partnerships which are based on contract structures between the clients and the ESCOs [44] From the demand side, farmers (households) distrust the ESCOs for three reasons. First, the farmers have no knowledge of EPC projects and thus they are worrying whether the EPC could be working for the whole contract period. Second, it is doubtful that ESCOs being small and private companies will be able to provide investment and high-quality operational services. Third, without the supervision and participation of a third party, farmers are skeptical about the possibility of resolving disputes that may arise during the contract period. From the supply side, ESCOs are not very willing to cooperate with farmers for four reasons. First, farmers are different in cultures and ethnicity, income, living standards and lifestyles. It is a great challenge that a standardized EPC contract is fitting for all households. Second, farmers are used to burning raw coal and unprocessed biomass and it is difficult to have them accept new energy and pay more. Third, a 7-10-year contract may not be feasible for rural households, since rural houses are usually in poor quality in terms of quality and energy efficiency, and their house lifetime may be shorter than the contract period. Fourth, without intervention by local government and village committees, ESCOs are not confident in establishing long-term friendly cooperation with farmers, and thus there are great challenges for ESCOs dealing with all disputes during the contracting period.
2) Difficult to have payments directly from the household. Although EPC contracts have been signed, collecting payments directly from households can be extremely difficult. It is obvious that all ESCOs are very much concerned whether the payments could be done in line with the contract and on time. During the questionnaire surveys and, in particular, the in-site interviews, payment was the top issue that all respondents were concerned about.

3.4. The three modes designed by this research

There are different ways to structure an EPC mode with the considerations on different risk allocations between the two parties, provisions of finance, and repayment mechanisms of ESCOs [45]. The key point for designing the new modes is to remove the barriers that are found in applying the traditional EPC modes in rural energy services. Previous studies on applying EPC modes in rural energy

Table 4
The three EPC modes designed by this research.

Mode	Description	Expected advantages	Applicable households
A	Mode A is the traditional energy-cost trust mode. The contract will be signed between the household and ESCO and there is no third party involved. ESCO is responsible for investment, operation, maintenance, and monitoring. Households will pay, based on the agreed energy price, which is normally lower than the market price.	This traditional mode has been proven, and there are tremendous experiences available from the EPC market. There are also national technical guidelines and regulations available for making sure the mode is functional.	Villages are near cities, and the heating system of households is connected to the urban central heating system.
B	Mode B is an adapted EPC mode. The key point is that local government is involved in the mode. EPC contract will be signed by the household, ESCO, and local government. Instead of ESCO collecting payments directly from the household, the local government will collect payments from the household and then the local government will pay ESCO, based on the contract. Local government will also provide subsidies to the poverty households for ensuring the payment.	The great advantage is the guarantee of payment made by the local government. This will ensure ESCO's benefits and mobilize ESCO's interests in cooperating with household. Participation of the local government is more conducive to dispute resolution.	In the villages, where the main solution is to adopt heat pumps.
C	Mode C is adapted from mode A. The key difference is that, in mode C, ESCO will rent the household's roof space for the installation of a PV panel. Part of Electricity generated by PV panel will be provided to household free of charge. The rest electricity will be on the grid. Similar to mode A, there is no third party involved in the EPC contract.	Roof space for energy is attractive for both households and ESCO. There is no need that ESCO to collect payment from households. Instead, ESCO will get payment from the national grid.	Areas are rich in solar resources. Not very cold in wintertime. The quality of farmers' houses should be ensured by the installation of PV panels.

services are limited and thus have not addressed properly those barriers in a practical way. Taking into account all findings generated from the questionnaire surveys and in-site interviews, in designing the new modes, emphasis should be placed on removing the barriers and giving due consideration to the following requirements.

1) Removing the doubts of both farmers and ESCOs and contributing to building mutual trust between farmers and ESCOs. Thus it would be wise to have the participation of an authoritative third party.
2) Designing a payment mechanism in which farmers pay on time and ESCOs are able to receive payments in accordance with the contractual payment amounts.
3) A highly efficient and workable supervision and monitoring mechanism for ensuring energy savings and households receiving high-quality services. Such a mechanism should also ensure that the agreed solutions must be completed on time and in high quality.
4) The designed new modes should facilitate the reduction of risks and, thus, increase access to financing.
5) Scalable, viable and bankable.

Based on the mentionedabove 5 requirements, we have designed three EPC modes in intensively cooperating with all stakeholders. The three modes are presented in Table 4, including mode description, expected advantages and conditions for applications.

Mode A acts as the baseline mode and it is the traditional energy-cost trust mode. This mode is mature and, when conditions are prepared, it is working very well. The key point of mode B is the participation of the local authorities as the third party. It is expected that local authorities will play the role of building mutual trust between households and ESCOs, assuring the payments from farmers on time and supervising the energy services provided by the ESCOs are in line with the contract. Mode C is adapted from mode A and the difference is that, in mode C, households (farmers) will also invest by way of renting their roof space for ESCOs installing PV panels. Similar to mode B, there is no need to collect payment from households in mode C.

3.5. *Testing the three modes*

Testing the three modes is conducted in the way of assessment of the EPC projects at the end of the 2nd year of the contracts. The assessment aims to monitor whether those 8 barriers identified before the EPC projects have been removed or reduced. Pre-coded questionnaires have been sent to all contracting parties to ask them to score the barriers. In addition, site visits and peer-to-peer exchanges between the target villages, selected households, local authorities and selected ESCOs have been conducted for an in-depth understanding of EPC project performance.

For mobilizing the participation of households, various awareness-raising campaigns have been conducted before the EPC contracting, in collaboration with the target villages, local authorities and ESCOs. Besides, trainings for different stakeholders are also implemented for building up knowledge and capacities in understanding EPC concepts and implementing EPC contracts. The campaigns mobilize households to participate in the pilots by informing them about the benefits of systematic energy retrofitting solutions, energy efficiency behavior, and available financing options. The campaigns also inform households that future rural energy consumption policies will be low-carbon, clean and sustainable. Participation in the EPC projects will have a head start in adapting to future energy consumption policies. The campaigns and trainings have mobilized 24000 households and 25 ESCOs from the provinces of Henan and Gansu to participate in the pilot action.

Among the 24000 households, 286 households have chosen the mode A. Those 286 households are near cities and their heating system is connected to an urban central heating system. 11835 households have chosen Mode B, and most of those households are from Gansu province, as compared to the central province of Henan, they are not rich in solar and it is very cold in winter. The rest 11879 have chosen mode C and most of them are from Henan Province. Among the 24000 questionnaire surveys, 21230 have responded, of which 251 respondents are from mode A, 10415 are from mode B and the rest 10564 are from mode C. The total response rate is 88.5 %.

All testing results are presented in Tables 5–7.

Table 5
Mode A: testing results
Number of EPC contracts:286, number of respondents: 251, responding rate: 87.8 %.

The 8 identified barriers	Score before the piloting	Score after two-years piloting	Change of the score in %
1) Lack of trust between rural households and ESCOs	9.6	9.1	−5.2 %
2) Poor quality of rural houses that do not meet the criteria of installations of facilities.	8.3	7.7	−7.2 %
3) Low willingness to adopt the EPC mode.	8.2	7.8	−4.9 %
4) Contracts are not clearly clarified and not in enough details	8.3	8.0	−3.6 %
5) Relatively high operational costs	8.2	7.8	−4.9 %
6) Lack of financing	8.3	8.1	−2.4 %
7) Difficult to have payments directly from household	9.6	9.3	−3.1 %
8) Delay in payment.	8.6	8.2	−4.7 %
Average	8.6	8.2	−4.6 %

Source: Primary data 2023

Table 5 shows that, although various campaigns and trainings are conducted before the signing of the EPC contracts, barriers encountered in the implementation of the traditional mode A has not decreased significantly. Among the 8 barriers, there is no one that its score decreased by more than 8 %, with an average decrease of 4.6 %. Based on the testing result of mode A and findings generated from the literature reviews and status assessment, we argue that, due to the obvious conditional differences, the traditional EPC modes are not well functioning in rural energy service and necessary adaptations must be made when designing and applying EPC modes in rural areas.

Most barriers have been removed when adopting mode B, and, as presented in Table 6, the overall score of barriers decreases significantly by 43.0 %. The most two serious barriers of lack of trust between rural households and ESCOs and difficulty in having payments directly from households decreased by more than 60 %. Excepting the barrier of relatively high operational costs that decrease by 4.9 %, all barriers decrease by more than 20 %. Taking into account the testing result presented in Table 6 and our peer-to-peer exchanges with the stakeholders, we argue that the participation of the third party in the EPC contract is the key to the success. Thus mode B is identified as an adapted EPC mode that is well-functioning and can be disseminated in rural energy services. Participation of local authorities as the third party also favors the settlement of disputes, which is the riskiest factor for all EPC contracts [46–49].

The desired result also appears in mode C, in which the overall score of the 8 barriers decreases by 48.8 %. In particular, the most serious barrier of difficulty to have payments directly from household decreases by 68.8 %. We argue payment that has been one of the key risks in most EPC projects (reference) is no longer the important issue in mode C. Although no third party is involved, mode C has generated very good results in building mutual trust between clients (households) and ESCOs, given the fact that households get a very satisfactory return from renting out their roof spaces. It is obvious that the poor quality of rural houses that do not meet the criteria for installations of PV panels is still a serious barrier in mode C. As presented in Table 7, lack of financing is also a barrier in mode C. Mode C is a pure business mode with no local government involvement. We conclude that mode C is scalable, viable and bankable, and thus feasible for rural energy services when the solution is adopting PV technology.

The main result of this research has proven that EPC modes can be well-functioning in rural contexts if the traditional modes are adapted to rural conditions. Although the four questions presented in the section Introduction have been addressed in this research, we suggest that cultural and social elements that are neglected in this research should be well considered in the design of the adapted EPC modes in future studies and practices.

4. Discussions and conclusions

China faces a great challenge in achieving carbon neutrality in rural areas. To address this challenge, it is crucial to develop and promote energy service models that are appropriate for rural conditions. Successful EPC experiences have made many academics and policymakers favorable to the implementation of EPC modes in rural areas [50]. Over the last decade, very few literature address the issue of EPC performance in rural energy services [51,52]. Our surveys on a limited number of ongoing rural EPC projects suggest that the traditional EPC modes are not well functioning within the rural context. Based on questionnaire surveys on a limited number of ongoing EPC projects, we conclude that the traditional EPC modes are difficult to work in the rural context, mainly because of a number of key insurmountable barriers that are identified by this research.

Based on the specific conditions, living habits, and cultural background of rural areas, and by working with stakeholders such as farmers, ESCOs, local governments, and village committees, three EPC modes are developed by this study, which also takes into account the fact that the main measure for rural energy services is the use of technologies such as solar energy and heat pumps. Rural villages in general are rich in solar energy and heat pumps and have a large space, which makes them uniquely suited to promote the use of these two low-carbon and clean energy sources.

These three modes are designed for different rural scenarios. Mode A is the traditional mode, which is more suitable for rural areas close to cities, which are in urbanizing areas, with relatively high population density and limited space, and households in these areas already enjoy urban centralized heating services, and are therefore more suitable to the traditional EPC model. Mode B is suitable for

Table 6
Mode B: testing results
Number of EPC contracts: 11835, respondents: 10415, responding rate: 88 %.

The 8 barriers	Score before the piloting	Score after two-years piloting	Change of the score in %
1) Lack of trust between rural households and ESCOs	9.6	3.4	−64.6 %
2) Poor quality of rural houses that do not meet the criteria of installations of facilities.	8.3	6.5	−21.7 %
3) Low willingness to adopt the EPC mode.	8.2	4.4	−46.3 %
4) Contracts are not clearly clarified and not in enough details	8.3	4.0	−51.8 %
5) Relatively high operational costs	8.2	7.8	−4.9 %
6) Lack of financing	8.3	5.5	−33.7 %
7) Difficult to have payments directly from household	9.6	3.7	−61.5 %
8) Delay in payment.	8.6	4.2	−51.2 %
Average	8.6	4.9	−43.0 %

Source: Primary data 2023

Table 7
Mode C: testing results
Number of EPC contracts: 11879, respondents: 10564, responding rate: 88.9 %.

The 8 barriers	Score before the piloting	Score after two-years piloting	Change of the score in %
1) Lack of trust between rural households and ESCOs	9.6	4.0	−58.3 %
2) Poor quality of rural houses that do not meet the criteria of installations of facilities.	8.3	7.0	−15.6 %
3) Low willingness to adopt the EPC mode.	8.2	4.0	−51.2 %
4) Contracts are not clearly clarified and not in enough details	8.3	3.8	−54.2 %
5) Relatively high operational costs	8.2	4.0	−51.2 %
6) Lack of financing	8.3	6.0	−27.7 %
7) Difficult to have payments directly from household	9.6	3.0	−68.8 %
8) Delay in payment.	8.6	3.7	−57.0 %
Average	8.6	4.4	−48.8 %

Source: Primary data 2023

rural areas where heat pump technology is adopted. If the traditional EPC model is adopted, it will be difficult for ESCOs to receive payments for their services from the households. Therefore, the traditional customer-ESCO contract model is not well functioning and the intervention of a third party is required. This third party is the local government. In Model B, the main role of the local governments is to use their existing tariff channels to collect the energy tariffs at a lower price than the energy price before the EPC project, which is already specified in the EPC contract. The energy tariffs collected by the government will be then transferred to the ESCOs, and for those poor families who cannot afford to pay the energy tariffs, the local government will spend the money from the special fund for poverty alleviation to ensure that the ESCOs will receive the tariffs in full and on time. This greatly reduces the risk to the ESCO. Model C is adapted from the traditional customer-ESCO contract model. In Model C, farmers rent their roofs to ESCOs to install solar panels. Part of the electricity generated by the solar panels is provided free of charge to the farmer and the rest is connected to the grid. ESCOs make profits from the grid, and farmers use the energy free of charge. At the end of the contract, the solar panels belong to farmers. This model also eliminates the hassle of ESCOs charging farmers directly for energy, and the ESCOs' profits are more stable and less risky.

This research shows that the main barriers encountered in the operation of Mode A decreased slightly (8 barriers, with an average decrease of 4.6 %). The barriers in the operation of Mode B and C decrease significantly, by 43.0 % and 48.8 % respectively. The tests went satisfactorily. Our main conclusion is that the traditional EPC modes, with adaptations, can be applied to a wide range of rural areas and they are feasible, scalable, viable and bankable.

Policy cycle theory points out that PDCA (plan, do, check/assessment, action/adaptation) is the essential principle of leaning by doing and fostering policy development properly. Building on the PDCA principle, the findings, and the conclusions made in this research, this paper makes suggestions to the policymakers on deepening and upscaling EPC in rural energy services. The existing EPC polices and technical guidelines developed within the urban context of energy management must be adapted to rural conditions in the way of taking into account the rural diversities of culture, lifestyles, income, ethnic groups as well as natural conditions. No one EPC mode fits all [53,54].

EPC can play an important role in addressing challenges in achieving rural carbon neutrality. Thus policy framing is needed to involve third parties, improving the quality and operability of EPC contracts, reducing risks, and removing barriers. Participation of the third party in an EPC contract is an effective way of addressing challenges and reducing and removing barriers from rural EPC projects. Thus governments at both national and local levels are suggested to conduct a systematic result-oriented monitoring and evaluation and then formulate relevant principles and guidelines for involving third parties in rural EPC projects. Given to the great potential of energy savings and reduction of carbon emission, effectively combining the implementation of rural EPC projects and rural carbon asset management, and incorporating rural EPC projects into the carbon emissions trading system will help to increase the attractiveness of rural EPC projects and press more ESCOs to participate. Financing has been always a crucial issue in any EPC project, and thus exploring alternative financing modes such as green and low-carbon financing could make EPC more accessible to rural households. It is recommended that the important role of digital technology should be included and addressed in future research. Results generated by this research would not recommend that farmers manage their energy consumption by themselves and it is suggested to out-contracting ESCOs by the modes developed and tested by this paper.

Ethics statement

Review and/or approval by an ethics committee was not needed for this study because there were no ethical issues involved in this study.

Funding

This work is financially supported by the EU Switch Asia project, entitled Promoting Sustainable Residential Energy Consumption in Rural China (Contract Number: ACA/2021/428-231). We would like to thank all the EPC projects involved in this survey and all the interviewees who contributed to this research.

Data availability statement

Data generated or analysed during this study is included in article. No additional data is available.

CRediT authorship contribution statement

Mingshun Zhang: Writing – review & editing, Writing – original draft, Validation, Project administration, Funding acquisition, Formal analysis, Conceptualization. **Ruoxin Li:** Writing – original draft, Methodology, Data curation, Formal analysis. **Chun Xia-Bauer:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30135.

References

[1] H. Yuan, X. Gao, C. Yang, Status, problems and development strategies of EPC in China, Energy Technology and Economics 23 (3) (2011) 58–66.
[2] X. Cao, S. Zhang, A research on barriers and strategies of development of Chinese ESCO, Construction Economy 10 (2010) 110–113.
[3] E. Mills, S. Kromer, G. Weiss, P.A. Mathew, From volatility to value: analyzing and managing financial and performance risk in energy-saving projects, Energy Pol. 34 (2) (2006) 188–199.
[4] Z. Lin, The fostering mechanism and organizational structure of EPC in building sector, Build. Sci. 28 (2) (2012) 8–11.
[5] P. Bertoldi, S. Rezessy, E. Vine, Energy service companies in European countries: current status and a strategy to foster their development, Energy Pol. 34 (2006) 1818–1832.
[6] Y. Kang, Y. Zhang, Z. Ying, Status and development of Chinese energy saving service sector, China Energy 32 (8) (2010) 29–32.
[7] X. Liang, Development and outlook of energy service sector in Chinese building sector, Construction Science and Technology 13 (2012) 11–15.
[8] P. Xu, H.W. Chan, H.J. Visscher, J. Zhang, Z. Wu, Sustainable building energy efficiency retrofit for hotel buildings using EPC mechanism in China: analytic Network Process (ANP) approach, J. Clean. Prod. 107 (2015) 378–388, 2015.
[9] T. Yoshioka, M. Furukawa, K. Yoshizaki, R. Matsuhashi, Y. Yoshida, Financial risk management for energy service project under the Tokyo emission trading system, Stoch. Environ. Res. Risk Assess. 25 (2011) 677–683, 2011.
[10] S. Sorrell, The economics of energy service contracts, Energy Pol. 35 (2007) 507–521.
[11] E. Vine, An international survey of the energy service company (ESCO) industry, Energy Pol. 33 (2005) 691–704.
[12] A. Iimi, Multidimensional auctions for public energy efficiency projects: evidence from Japanese ESCO market, Rev. Ind. Organ. 49 (2016) 491–514, 2016.
[13] P. Principi, R. Fioretti, A. Carbonari, M. Lemma, Evaluation of energy conservation opportunities through energy performance contracting: a case study in Italy, Energy Build. 128 (2016) 886–889, 2016.
[14] P. Bertoldi, B. Boza-Kiss, Analysis of barriers and drivers for the development of the ESCO markets in Europe, Energy Pol. 107 (2017) 345–355.
[15] A. Marino, P. Bertoldi, S. Rezessy, et al., A snap shot of the European energy service market in 2010 and policy recommendations to foster a further market development, Energy Pol. 39 (2011) 6190–6198.
[16] L. Huimin, Z. Xinyue, H. Mengyue, Game-theory-based analysis of energy performance contracting for building retrofits, J. Clean. Prod. 231 (2019) 1089–1099, 2019.
[17] T. Shang, K. Zhang, P. Liu, Z. Chen, A review of energy performance contracting business models: status and recommendation, Sustain. Cities Soc. 34 (2017) 203–210, 2017.
[18] J. Töppel, T. Tränkler, Modeling energy efficiency insurances and energy performance contracts for a quantitative comparison of risk mitigation potential, Energy Econ. 80 (2019) 842–859.
[19] T. Winther, Energy performance contracting (EPC): a suitable mechanism for achieving energy savings in housing cooperatives? Results from a Norwegian pilot project, Energy Effic 10 (2017) 577–596.
[20] Z. Hu, When energy justice encounters authoritarian environmentalism: the case of clean heating energy transitions in rural China, Energy Res. Social Sci. 70 (December 2020) 101771.
[21] L. Guoliang, Z. Xinghua, Universalization of access to modern energy services in Tibetan rural households—renewable energy's exploitation, utilization, and policy analysis, Renew. Sustain. Energy Rev. 16 (5) (June 2012) 2373–2380.
[22] H. Zhijia, W. Fang, l. Yuehong, C. Xiaofeng, W. Qiqi, Optimization model for home energy management system of rural dwellings, Energy 283 (2023) 129039.
[23] Z. Xianguo, Z. Yanan, C. Zhiyong, Development and research of rural renewable energy management and ecological management information system under the background of beautiful rural revitalization strategy, Sustainable Computing: Informatics and Systems 30 (June 2021) 100553.
[24] R. Hongbo, W. Qiong, R. Jianxing, G. Weijun, Cost-effectiveness analysis of local energy management based on urban–rural cooperation in China, Appl. Therm. Eng. 64 (Issues 1–2) (March 2014) 224–232.
[25] Z. Yuanrong, E. Meredydd, Yu Sha, S. Xiaoliang, W. Juemin, Linkages between policy and business innovation in the development of China's energy performance contracting market, Energy Pol. 140 (May 2020) 111208.
[26] Mengsi Deng, Rongjiang Ma, Fei Lu, Yazhou Nie, Li Pengchao, Xingli Ding, Yanping Yuan, Ming Shan, Xudong Yang, Techno-economic performances of clean heating solutions to replace raw coal for heating in Northern rural China, Energy Build. 240 (2021).
[27] Yifei Bai, Weirong Zhang, Xiu Yang, Wei Shen, Yu Yang, The framework of technical evaluation indicators for constructing low-carbon communities in China, Buildings 11 (10) (2021).
[28] Yiyun Zhu, Xiaona Fan, Changjiang Wang, Guochen Sang, Analysis of heat transfer and thermal environment in a rural residential building for addressing energy poverty, Appl. Sci. 8 (11) (2018).
[29] Cristina Dominguez, Orehounig Kristina, Carmeliet Jan, Understanding the path towards a clean energy transition and post-electrification patterns of rural households, Energy for Sustainable Development 61 (2021).
[30] Ren Wang, Zhujun Jiang, Energy consumption in China's rural areas: a study based on the village energy survey, J. Clean. Prod. 143 (2016).

[31] T. Prabatha, K. Hewage, R. Sadiq, An energy performance contract optimization approach to meet the competing stakeholder expectations under uncertainty: a Canadian case study, Sustainability 14 (2022) 4334, https://doi.org/10.3390/su14074334.
[32] K. Guo, L. Zhang, Guarantee optimization in energy performance contracting with real option analysis, J. Clean. Prod. 258 (2020) 120908, 2020.
[33] D. Brown, Business models for residential retrofit in the UK: a critical assessment of five key archetypes, Energy Effic 11 (2018) 1497–1517.
[34] Z. Yu, J. Wu, W. Xu, Building Energy Performance Contracting, Construction Science and Technology (Special Issue: Energy Saving Service), 2012, pp. 32–35.
[35] M. Zhang, M. Wang, C. Xia-Bauerc, Managing energy efficiency of buildings in China: a survey of energy performance contracting (EPC) in building sector, Energy Pol. 114 (2018) 13–21.
[36] C. Nolden, S. Sorrell, The UK market for energy service contracts in 2014–2015? Energy Efficiency 6 (2016) 1405–1420, 2016.
[37] M. Aasen, H. Westskog, K. Korneliussen, Energy performance contracts in the municipal sector in Norway: overcoming barriers to energy savings? Energy Efficiency 9 (2016) 171–185, 2016.
[38] G. Liu, B. Lei, Inspiration of European EPC experiences for China, Energy Saving and Environmental Protection 9 (2009) 25–28.
[39] Z. Wang, G. Xu, R. Lin, H. Wang, J. Ren, Energy performance contracting, risk factors, and policy implications: identification and analysis of risks based on the best-worst network method, Energy 170 (March 2019) 1–13.
[40] P. Xu, H.W. Chan, Q.K. Qian, Success factors of energy performance contracting (EPC) for sustainable building energy efficiency retrofit (BEER) of hotel buildings in China, Energy Pol. 39 (11) (2011) 7389–7398, 2011.
[41] T. Meshcheriakova, N. Verstina, Methodic approach to energy costs reduction on the basis of the energy service contract, Adv. Intell. Syst. Comput. 692 (2018) 1136–1150, 2018.
[42] R. Lv, J. Wang, Comparative study on China-overseas energy performance contracting, Sino-global Energy 16 (2011) 22–28.
[43] X. Zhang, X. Li, S. Chen, Problem and countermeasure of energy performance contracting in China, Energy Proc. 5 (2011) 1377–1381.
[44] Y. Zhou, M. Evans, S. Yu, X. Sun, J. Wang, Linkages between policy and business innovation in the development of China's energy performance contracting market, Energy Pol. 140 (May 2020) 111208.
[45] Nunzia Carbonara, Roberta Pellegrino, Public-private partnerships for energy efficiency projects: a win-win model to choose the energy performance contracting structure, J. Clean. Prod. 170 (2018) 1064–1075.
[46] T Urmee Nurcahyanto, Development of energy service company (ESCO) market to promote energy efficiency programmes in developing countries. Transition towards 100, in: Renewable Energy. Innovative Renewable Energy, Springer, 2018, pp. 283–294, 2018.
[47] R. Hongquan, G. Xin, M. Chaoxuan, Empirical study on annual energy-saving performance of energy performance contracting in China, Sustainability 10 (2018) 1666, https://doi.org/10.3390/su10051666.
[48] C. Carpino, R. Bruno, V. Carpino, N. Arcuri, Uncertainty and sensitivity analysis to moderate the risks of energy performance contracts in building renovation: a case study on an Italian social housing district, J. Clean. Prod. 379 (Part 2) (2022) 134637.
[49] D.N. Karamov, Autonomous renewable energy systems in Russia. Critical review of the current situation, Energy Rep. 6 (9) (2020) 31–37, 2020.
[50] P. Lee, P.T.I. Lam, W.L. Lee, Performance risks of lighting retrofit in energy performance contracting projects, Energy Sustain Dev 45 (2018) 219–229, 2018.
[51] M. Frangou, M. Aryblia, S. Tournaki, T. Tsoutsos, Renewable energy performance contracting in the tertiary sector standardization to overcome barriers in Greece, Renewable Energy 125 (2018) 829–839.
[52] T. Shang, L. Yang, P. Liu, K. Shang, Y. Zhang, Financing mode of energy performance contracting projects with carbon emissions reduction potential and carbon emissions ratings, Energy Pol. 144 (September 2020) 111632.
[53] M. Beerepoot, N. Beerepoot, Government regulation as an impetus for innovation: evidence from energy performance regulation in the Dutch residential building sector, Energy Pol. 35 (10) (2007) 4812–4825.
[54] X. Yuan, R. Ma, J. Zuo, R. Mu, Towards a sustainable society: the status and future of energy performance contracting in China, J. Clean. Prod. 112 (Part 2) (20 January 2016) 1608–1618.