Contract decisions analysis of shared savings energy performance contracting based on Stackelberg game theory

Xun Zhang *[a]

[a] School of Management**,** SHANGHAI University, Shanghai, 201800, China;

ABSTRACT: Energy Performance Contracting is a contractual arrangement between energy users and Energy Service Companies (ESCOs) and is currently the main mechanism for implementing energy-saving retrofitting measures in existing buildings. The paper centers around the decision-making conundrum pertaining to the energy-saving sharing percentage and initial project investment within the realm of shared savings Energy Performance Contracting. By formulating a Stackelberg game-based decision-making game model, we examine the optimal contract decisions of both the energy user and the ESCO. The results of numerical experiments demonstrate that this method yields significant advantages for both energy users and ESCOs. Additionally, we observed that the employment of more sophisticated energy-saving technologies by the ESCO and a higher share of investment by the energy users result in superior energy-saving efficiency.

1. INTRODUCTION

Energy conservation and emission reduction are essential issues that China and the world will pay attention to in the future. There are at least 40% of global energy consumed and more than 30% of greenhouse gas emissions produced by buildings1. The traditional model of energy-saving retrofitting in buildings is to implement energy-saving efficiency projects by energy users as independent individuals. However, it is difficult for energy users to retrofit buildings alone due to some barriers[2,3]. First, Energy users do not have professional knowledge of energy-saving retrofit, which leads to the unreasonable selection of energy-saving equipment and formulation of energy-saving plans for buildings, resulting in secondary waste of energy. Second, the traditional model of energy-saving retrofitting in buildings is not supported by the financial market but still requires energy users to finance the purchase of expensive energy-efficiency equipment, making it difficult for energy users to finance. Energy Performance Contracting (EPC) represents a contractual arrangement between Energy Service Companies (ESCOs) and energy users, offering an effective solution to overcome these barriers related to energy performance4. The difference between the traditional energy retrofitting model and EPC is shown in Figure. 1. However, energy users and ESCOs in EPC depend on each other and constrain each other, so how to help the decision-making of energy users and ESCOs is an important issue to increase their active participation in EPC projects.

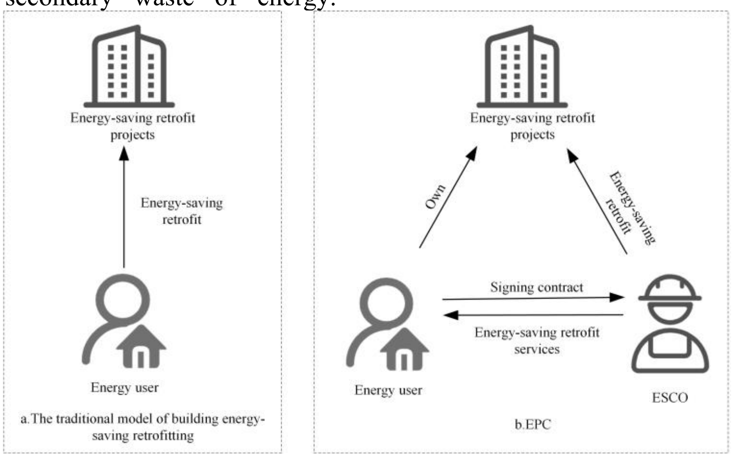

Figure 1. Comparison of different energy-saving retrofit models.

The utilization of EPC, as an advanced energy management strategy and a market-driven mechanism for energy conservation, allows for the recovery of expenses associated with implementing, operating, and

* Corresponding author: zhangxun21720730@shu.edu.cn

maintaining energy-saving measures through the resulting energy savings5. On the one hand, the mechanism can assign the task of energy-saving retrofit to ESCOs with professional energy-saving knowledge. On the other hand, it can ease the financing pressure on energy users. Nowadays, the main business models of EPC are divided into Guaranteed Savings Model6, Shared Savings Model7, and Energy Costs Hosting Model8. ESCO Committee of China Energy Conservation Association stated the total number of energy-saving renovation projects executing Shared Savings Model projects accounts for 50% of the total energy-saving retrofit projects in 2021. Through this mechanism, energy users who lack both awareness and adequate funding for Building Energy-Saving Retrofit are encouraged to join the EPC projects voluntarily9. Because of the model's broad applicability, it is better suited to China's current energy service development stage. Thus, this model occupies the leading position in China's EPC industry and has significant growth potential.

The allocation of energy savings benefits is critical to the success of Shared Savings EPC projects. Indeed, the scheme for allocating total energy savings and benefits directly affects energy users' and ESCOs' profits. Currently, few scholars have focused on the distribution of benefits under Shared Savings Model. Mills et al.10 developed a framework to help managers manage risks in energy-saving retrofitting projects. Xing et al.11 used the robustness of the Shared Savings Model to build a bidirectional moral hazard of the benefit distribution. Xu et al.14 and Liu et al.15 indicated that there is essentially a non-cooperative game relationship between energy users and ESCOs. However, the issue has only been explored in a few studies.

Based on the above analysis, this paper will establish a Stackelberg game analysis model to help energy users and ESCOs to allocate their benefits. The remaining sections of this paper are organized as follows: Section II analyzes the decision-making process between energy users and ESCOs, describes the main symbols and their definitions, and establishes the Stackelberg game analysis model between energy users and ESCOs under Shared Savings Model; Section III is numerical simulations of the model. for both sides of the game and the government. The conclusions of this paper are given in Section IV.

2. METHODOLOGY

2.1 Problem Description

In EPC projects, the energy user has ownership of the energy retrofit project and can decide whether to implement the energy management contract or not and occupies the dominant position in the EPC project. The dependency and constraints between the energy users and the ESCOs involve the energy retrofitting period and the project operation period, in which the game process between the two parties and the benefits and costs during the project operation period are shown in Figures. 2 and 3, respectively.

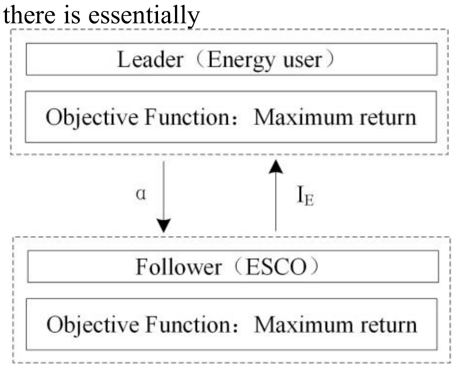

Figure 2. Decision-making process of game parties.

Figure. 2 shows that in Shared Savings EPC, the Energy user informs the ESCO of the total energy cost ($e \cdot p$), and both parties agree on the sharing ratio of investment β , $0 \le \beta \le 1$, the contract period T_E , and pre-determine the sharing ratio of energy efficiency benefits α , $0 \le \alpha \le 1$, in the project. The ESCO will adjust the investment amount I_E and the corresponding energy-saving ratio $S(I_E)$ under the investment amount according to its own conditions, and help the energy user to obtain part of the energy-saving benefit $(1-\alpha)ep\left(1-S(I_E)\right)$ in each year of the contract period and all of the energy-saving benefit in the non-contract period $ep\left(1-S(I_E)\right)$, under the given energy-saving sharing ratio by the energy user. The ESCO receives the rest of the annual energy savings $\alpha \cdot ep\left(1-S(I_E)\right)$ during the contract period, and bears the operation and maintenance(O&M) costs of the project during the contract period T_E , according to the contract. In determining its optimal investment, the ESCO is bound by its own maximum investment amount I_{TE} , as is the EU, which has a maximum investment amount I_{TO} .This is because the EPC project investment is large and the ESCO needs to obtain financing from a financial institution, which will provide a loan based on the ESCO's past creditworthiness.

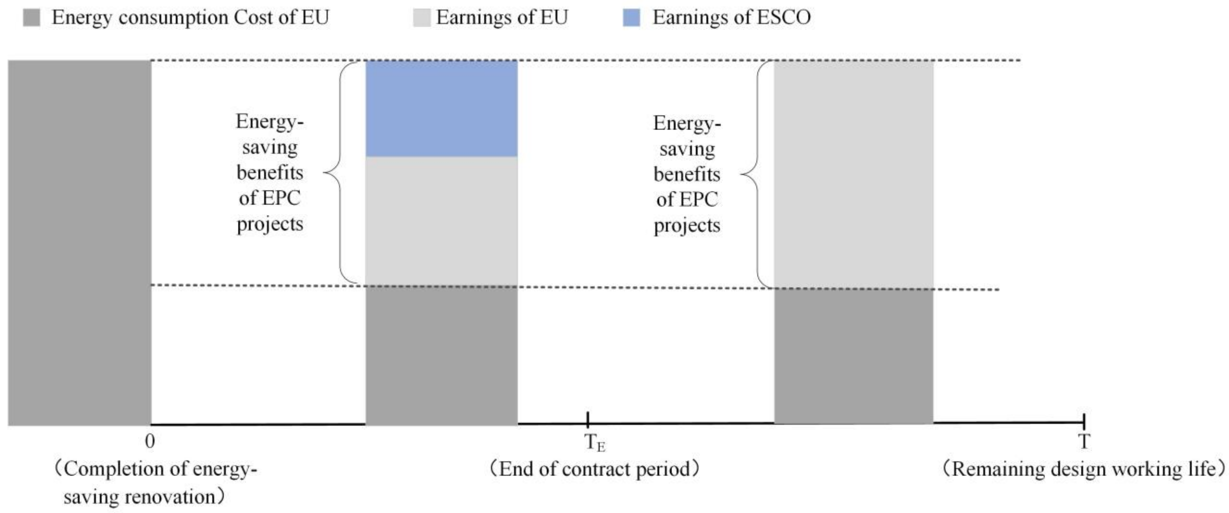

Figure 3. EPC project operation mechanism

At the end of the contract period, the ESCO transfers the retrofit project to the energy user, who receives all the energy-saving efficiency benefits $ep\left(1-S(I_E)\right)$ for the remaining design working life T_O of the retrofitted building and bears the operation and maintenance costs for the remaining design working life of the retrofitted building, as shown in Figure. 3. T is the remaining design working life of the retrofit project. It is the amount of time that the project can be used for its intended purpose without major repairs under conventional design, construction, use, and maintenance after the retrofit.

2.2 Hypothesis and Description of Symbols

For better description and modeling, the following assumptions are made in this paper:

Hypothesis 1. The annual energy cost of the energy user is stable, i.e., the annual energy cost is ep .

Hypothesis 2. The percentage of energy savings after retrofitting is a concave function of increasing input capital, i.e. the function $S(I)$ satisfies $dS/dI \geq 0$, $d^2S/dI^2 \leq 0$. While increased investment in energy conservation strategies is typically associated with larger annual energy savings potential, research has shown that the marginal annual energy savings decrease as investment increases, akin to the law of diminishing marginal utility. Therefore, the function $S(I_E)$ is defined as Eq.(1)， where the parameter b serves as a metric for gauging the sophistication of energy-saving technologies utilized by ESCOs[14].

$$S(I_E)=1-(1+a\frac{I_E}{1-\beta})^{-b} \quad (1)$$

Hypothesis 3. In this paper, we refer to the general O&M costs function $M(t)=k\cdot t^2+m$, where $k,m>0$. The first part is the variable costs that increase over time. The second part of this function is fixed costs, such as labor costs.

Hypothesis 4. To ensure the reasonableness of the project, the remaining design working life of the EPC project in this paper is longer than the contract period, i.e. $T \geq T_E$.

Table 1. Main symbols and descriptions.

Symbols	Descriptions
	Parameters
e	Total energy consumed by energy-using buildings before the implementation of EPC
p	The energy price per kWh
β	The ratio of the investment from the energy user, $0\leq\beta\leq1$
T_E	The contract period of EPC
T	The remaining design working life of energy-saving retrofitting buildings
S	The sharing ratio of the energy savings， $0\leq S\leq1$
i	The discount rate
I_{TE}	The maximum amount of investment of ESCO
I_{TO}	The maximum investment amount of EU
I	The total investment of EPC projects
Π_E	The energy-saving benefits of ESCO
Π_O	The energy-saving benefits of EU

Decision variables	
α	The sharing percentage of the annual energy-savings, $0 \le \alpha \le 1$
I_E	The investment amount of ESCO

2.3 Model

Based on the specified parameters and underlying assumptions, the mathematical programming model can be formulated using the following equation.

$$\max_{\alpha} \prod_O = ep \cdot (1-(1+a\frac{I_E}{1-\beta})^{-b}) \cdot (\frac{(1+i)^T - 1}{i(1+i)^T} - \frac{(1+i)^{T_E} - 1}{i(1+i)^{T_E}} \cdot \alpha) - \sum_{t=T_E+1}^{T} \frac{k \cdot t^2 + m}{(1+i)^t} - \beta \cdot \frac{I_E}{1-\beta} \quad (2)$$

s.t. $0 \le \alpha \le 1$, (3)

$$\max_{I_E} \prod_E = \alpha \cdot ep \cdot (1-(1+a\frac{I_E}{1-\beta})^{-b}) \cdot \frac{(1+i)^{T_E} - 1}{i(1+i)^{T_E}} - \sum_{t=1}^{T_E} \frac{k \cdot t^2 + m}{(1+i)^t} - I_E, \quad (4)$$

s.t. $I_E \le I_{TE}$, (5)

$$\frac{\beta}{1-\beta} I_E \le I_{TO}, \quad (6)$$

$$ep \cdot (1-(1+a\frac{I_E}{1-\beta})^{-b}) \ge kT^2 + m, \quad (7)$$

$$\alpha \cdot ep \cdot (1-(1+a\frac{I_E}{1-\beta})^{-b}) \ge kT_E^2 + m, \quad (8)$$

$$I_E \ge 0. \quad (9)$$

Equation (2) comprises three terms. The first term represents the total energy-saving benefits obtained by the energy user throughout the remaining design working life of the buildings. These benefits are discounted to the present value of the year when the energy-saving retrofit of the energy-using building is completed. The second term represents the present value of O&M costs during the non-contract period, and the third term represents the investment costs of the energy user. Constraint (3) constrains the benefit allocation ratio. Equation (4) also consists of three terms. The first term represents the present value of benefits gained by the ESCO during the contract period, discounted to the year when the energy-saving retrofit is completed. The second term represents the present value of O&M costs during the contract period, and the third term represents the investment costs of the ESCO. Constraints (5) and (6) limit the investment amount of energy users and ESCOs to their respective investment ceilings. Constraints (7) and (8) ensure that the energy savings in the final year of O&M exceed the O&M costs. Constraint (9) imposes a non-negative constraint on investment costs.

3. NUMERICAL RESULTS AND DISCUSSION

3.1 Contract Decision Calculation Example

Referring to some of the data from Liu et al.15, this paper assumes that the Energy Service Company E undertakes an energy-saving retrofit project belonging to the Energy user O. The initial energy consumption costs of the retrofit project are 20,000 per year, and the remaining design working life is 15 years. The ratio of the investment from the energy user is 0.3. The discount rate is 5%. The O&M costs function of the energy-saving retrofit project in year t is $2t^2 + 200$. The ESCO analyzes the energy-saving ratio function based on past historical data to be $1-(1+0.04I_E/(1-\beta))^{-0.1}$. The maximum investment that can be undertaken by the energy user and the energy efficiency service company is 1500 and 3500 respectively.

The model was implemented using Matlab R2020b with the parameters mentioned above, and the results are shown in Table 2.

Table 2. Optimal decisions and results.

α	I_E	$\prod_E$	$\prod_O$
26.23%	1668	6935	63305

The data in Table II shows that the energy user proposes an optimal energy efficiency sharing ratio of 26.23%, and the optimal initial investment amount of the ESCO is 1,668. It means that the project requires an initial investment of 2,383, of which the energy user needs to provide 715 and the ESCO needs to provide 1,668. The ESCO uses 2,383 to implement building energy-saving efficiency retrofits for the energy user's energy-using building, is responsible for the building's O&M during the contract period, and pays for the O&M costs. After the end of the contract period until the end of the remaining design working life of the project, the energy user will be responsible for the operation and maintenance of the project. The overall benefit of the project is 70,240. The total benefits received by the energy user in the project are 63,305, and the profit achievable by the ESCO during the contract period is 6,935.

3.2 The Impacts of the Parameters

(1) **The sophistication of energy-saving technologies**. The results in Table III for the two main contract parameters for the different " sophistication of

energy-saving technologies of the ESCO" for b are as follows. The optimal sharing percentage of the energy-savings determined by the energy user tends to increase with b. The optimal initial project investment determined by the ESCO increases with b. The results of these two variables are determined by the dynamic game process between the energy user and the ESCO. After these two variables are determined, ESCO's profit follows the same trend as b. Both the profit of the energy user and the total project benefit increase with the increase of b. From the data in Table III, it also follows that the ratio of total project profit to initial investment at each ESCO technology level also increases as b increases. The above analysis shows that the increase in the level of the ESCO's capability advancement improves the profit margin per unit investment, brings higher energy efficiency and socio-economic benefits, and has a positive effect on the development of the EPC mechanism.

Table 3. The impact of b.

b	α	I_E	Π_E	Π_O	Total Profit
0.10	26.23%	1669	6934	63305	70239
0.11	25.42%	1697	7363	68934	76297
0.12	24.66%	1713	7736	74295	82031
0.13	23.95%	1721	8059	79396	87455
0.14	23.27%	1720	8336	84247	92583

(2) **The ratio of the investment from the energy user**. The results in Table IV for different "investment sharing ratios" for β are as follows. The initial investment decided by the ESCOs is opposite trend to β, and the benefit sharing ratio decided by the energy user is also opposite trend to β. This is because the ESCOs have to get a higher share percentage of the energy-savings by increasing their own investment. After these two variables are determined, the ESCO profit decreases with the increase of β, and the profit of the energy user and the total project profit increase with the increase of β. From the above analysis, it is clear that energy user with a higher share of investment can generate higher energy-saving benefit themselves and higher total project revenues. Such energy users are more likely to participate in EPC projects for energy-saving efficiency retrofits. ESCOs with high financing pressure should also give priority to such energy users to relieve investment pressure and generate greater social energy efficiency benefits.

Table 4. The impact of β

β	α	I_E	Π_E	Π_O	Total Profit
0.2	27.36%	1753	7124	62211	69335
0.25	26.84%	1712	7034	62743	69777
0.30	26.23%	1669	6934	63305	70239
0.35	25.60%	1622	6824	63901	70725
0.40	24.94%	1573	6701	64535	71236

4. CONCLUSIONS

Energy Performance Contracting can improve the success rate of energy-saving retrofit projects of energy users, which is of great significance to the development of energy-saving in China. This paper focuses on the decision making of the contract in Shared Savings Model, where the decision variable of the energy user is the sharing percentage of the annual energy-savings and the decision variable of the ESCO is its own investment amount. This paper further establishes the Stackelberg game analysis model to analyze the decision-making process of both sides of the game, and obtains the following conclusions: (1) The improvement in the level of ESCO energy-saving technology can improve the profitability of the project's unit investment, increase the overall revenue, and bring higher energy efficiency and socio-economic benefits. It has a positive effect on the development of the EPC mechanism. (2) ESCOs with high financing pressure may prefer to choose energy users that decide to share a higher ratio of investment. Such action can help ESCOs to relieve financing pressure and also increase the total return of EPC projects.

REFERENCES

1. Yang L., Xia J.J, Shen Q. Establishing target-oriented energy consumption quotas for buildings. Utilities Policy, 41: 57-66 (2016).
2. Wilson C, Crane L, Chryssochoidis G. Why do homeowners renovate energy efficiently?

Contrasting perspectives and implications for policy. Energy Research & Social Science, 7: 12-22 (2015).

3. Zhang B.Z., Guo H.D., Zhao Q.Q., Zhang H.Y. Benefit coordination of loan financing of energy service company in existing building energy saving. Building Science, 31: 142-147 (2015).
4. Xu P.P., Chan E. H. ANP model for sustainable Building Energy Efficiency Retrofit (BEER) using Energy Performance Contracting (EPC) for hotel buildings in China. Habitat International, 37: 104-112 (2013).
5. Liu H.M., Hu M.Y., Zhang X.Y. Energy Costs Hosting Model: The most suitable business model in the developing stage of Energy Performance Contracting. Journal of Cleaner Production, 172: 2553-2566 (2018).
6. Limaye D. R., Limaye E. S. Scaling up energy efficiency: the case for a Super ESCO. Energy Efficiency, 4(2): 133-144 (2011).
7. Qian D., Guo J. Research on the energy-saving and revenue sharing strategy of ESCOs under the uncertainty of the value of Energy Performance Contracting Projects. Energy Policy, 73: 710-721 (2014).
8. Goldman C. A., Hopper N. C., Osborn J. G. Review of US ESCO industry market trends: an empirical analysis of project data. Energy policy, 33(3): 387-405 (2005).
9. Xu P.P., Chan E. H., Qian Q. K. Success factors of energy performance contracting (EPC) for sustainable building energy efficiency retrofit (BEER) of hotel buildings in China. Energy policy, 39(11): 7389-7398 (2011).
10. Mills E., Kromer S., Weiss G., Mathew P. From volatility to value: analysing and managing financial and performance risk in energy savings projects. Energy Policy, 34(2): 188-199 (2006).
11. Xing G.Y., Qian D., Guo J. Research on the participant behavior selections of the energy performance contracting project based on the robustness of the shared savings contract. Sustainability, 8(8): 730 (2016).
12. Qian D., Guo J. Research on the energy-saving and revenue sharing strategy of ESCOs under the uncertainty of the value of Energy Performance Contracting Projects. Energy Policy, 73: 710-721 (2014).
13. Shang T.C., Zhang K., Liu P.H., Chen Z.W., Li X.P., Wu X. What to allocate and how to allocate?—Benefit allocation in Shared Savings Energy Performance Contracting Projects. Energy, 91: 60-71 (2015).
14. XU X.Y., WU H.H. Contract decisions analysis of guaranteed savings energy performance contracting based on game theory. Operations Research and Management Science, 24(3): 112 (2015).
15. Liu H.M., Zhang X.Y., Hu M.Y. Game-theory-based analysis of Energy Performance Contracting for building retrofits. Journal of cleaner production, 231: 1089-1099 (2019).