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From CAPEX to OPEX: assessing the sustained impact of Energy-as-a-Service (EaaS) on PV-plus-storage adoption willingness in China's C&I sector

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Abstract. Against the backdrop of China's "Dual Carbon" goals, a significant adoption paradox persists in the deployment of distributed PV-plus-storage systems across the Commercial and Industrial (C&I) sectors. The fundamental reason lies in the fact that under the traditional CAPEX model, business owners have to bear high initial investment costs and also lack operational resources. Based on the Service-Dominant (S-D) Logic and Transaction Cost Economics, this paper studies the role of the "Energy as a Service" (EaaS) model (referred to as EMC in China) in enhancing the willingness to lay out infrastructure. Empirical evidence shows that EaaS has significantly enhanced the willingness of business owners to invest by means of off-balance-sheet financing mechanisms and risk transfer. Although EaaS still faces issues such as credit risks and electricity spot market volatility, the model's market effectiveness has been confirmed through authoritative data and real cases.

Keywords: Energy-as-a-Service (EaaS), Energy Performance Contracting (EMC), adoption willingness, C&I PV-plus-storage systems

1. Introduction

At present, reducing energy consumption and promoting sustainable development are the core strategic goals of China. With the continuous deepening of urbanization, the energy consumption of buildings alone accounts for 32% of the total global terminal energy consumption [1]. China is on track to achieve its carbon neutrality goals, aiming to peak carbon emissions by 2030 and achieve carbon neutrality by 2060. Energy investment in Commercial and Industrial (C&I) sectors across the country has reached new highs. According to the latest data from the International Energy Agency (IEA) and the National Energy Administration of China, the installed capacity of distributed photovoltaic power in China reached 118 GW in 2024 [2, 3].

By the beginning of 2025, the price of Chinese photovoltaic modules had dropped to a historical low of 0.07 - 0.09 US dollars per watt. The technology for the accompanying energy storage equipment was becoming increasingly sophisticated, and the price per watt-hour was constantly approaching the cost price. However, in the huge market of Small and Medium-sized Enterprises (SMEs) in China's commercial and industrial sectors, there was still a significant Adoption Paradox. On one hand, domestic policies have

encouraged enterprises to use green electricity, and the cost of PV-plus-storage systems has been rapidly decreasing. On the other hand, over 90% of existing buildings do not meet energy conservation requirements, leading a large number of business owners to be hesitant to deploy solar-plus-storage systems [4]. The main reason why business owners are reluctant lies in the traditional CAPEX model, where they have to deal with issues such as high upfront investment costs and long investment payback periods. Therefore, this paper aims to explore how the Energy as a Service (EaaS) model (referred to as Energy Management Contracting (EMC) in China) can be implemented and enhance the adoption intention of Chinese C&I owners. This study adopts a cross-disciplinary theoretical framework combined with empirical evidence from Chinese cases to analyze the decision-making mechanism of Chinese C&I owners, providing a decision-making reference with Chinese empirical support to solve the Adoption Paradox of distributed energy.

2. Theoretical foundation and analysis of China's barriers

2.1. The impact of Transaction Cost Economics (TCE) on business decisions

The TCE posits that economic agents encounter hidden costs in their decision-making beyond the actual prices of goods and services, including search costs, negotiation costs, and monitoring costs [1]. Due to the lack of transparent information channels (Lack of information), business owners who intend to purchase PV-plus-storage systems face significant information asymmetry: technical standards for PV-plus-storage systems, grid connection policies, and the complexity of the electricity spot market all constitute high professional barriers. As noted by Chang Hai, the reason why C&I owners are reluctant to adopt the PV-plus-storage system is not only the traditional CAPEX mentioned above, but also the hidden transaction costs brought about by the subsequent cumbersome manual inspections and system maintenance [5]. As Yang et al. pointed out, photovoltaic and storage devices have extremely high Asset Specificity. Once installed, it becomes difficult to remove and sell, turning into a Silent Cost that prevents enterprises from recovering their funds. As a result, it suppresses the willingness of business owners to purchase and install it themselves [1].

2.2. Debt aversion and implicit discount rate

In China, people prefer to save and maintain their cash flow rather than take on debt. As a result, some business owners exhibit strong "Debt Aversion". Even if a project is profitable, they tend to abandon it if debt financing is required. Schleich et al. found in their research that decision-makers have an extremely high implicit discount rate when evaluating Energy-Saving Technologies (EETs) [6]. This means that business decision-makers, due to their bounded rationality, pay more attention to the current cash flow rather than the total cost over the entire life cycle. The hyperbolic discounting model also explains that individuals are far more sensitive to current investments than to the perception of future returns [7].

2.3. Service-Dominant Logic (S-D Logic) re-defining products

The Service-Dominant (S-D) Logic proposed by Sarno and Siano offers a solution. Under the S-D Logic framework, energy is no longer a hardware product that enterprises need to purchase as per the Product-Dominant (P-D) logic. However, it is redefined as a service flow [8]. Decision-makers are concerned with the final outcome produced by the PV-plus-storage devices, rather than the ownership of the components. The EaaS model shifts the role of the owner from an asset holder (CAPEX) to a service beneficiary (OPEX), effectively resolving this contradiction.

3. The internal mechanism of eaas model in China

3.1. The off-balance-sheet financing mechanisms have been implemented in China

The EaaS model utilizes a third-party investment mechanism to achieve off-balance-sheet financing. Niemiec et al. have confirmed that the EaaS model is particularly suitable for institutions constrained by public debt ceilings or budget limitations [9]. The three mainstream EMC models in China are shown in Table 1. Take the project of China Shaanxi Mobile Company as an example. This project involves 898 sites and requires an investment of 39.1 million RMB for self-construction. The Shaanxi company ultimately chose the Shared savings contract and signed an EMC contract with a professional comprehensive service provider through the bidding process. The CAPEX that originally required nearly 40 million RMB was transformed into monthly OPEX, and the company also enjoyed the green electricity price that was lower than the original electricity rate [10]. It can be seen that the EMC model releases the company's working capital and mitigates its investment in Operational Resources [8], enabling the company to focus on its core business.

Table 1. The three EMC models in China [10]

Model type	Before the project renovation	After the project renovation	EMC model revenue
Shared saving contract	The investment in energy-saving measures will be covered by the Energy Service Companies (ESCOs), and the property owner does not need any financial contribution.	The owner shall pay a certain percentage of the cost of the energy-saving benefits generated by the project within a certain contract period.	ESCOs invest in energy-saving projects. They recover their investment through the sharing of energy-saving benefits and earn profits.
Energy cost hosting scheme	The owner entrusted the ESCOs to carry out the energy-saving renovation. After the acceptance, an agreement was made to pay a certain percentage of the renovation project investment.	After both parties have inspected and confirmed that the energy savings meet the requirements stipulated in the contract, the owner will pay the remaining balance of the contract, or use the energy-saving benefits for payment.	By managing the energy costs of energy-saving projects, the investment costs of the ESCOs can be recovered and profits can be obtained.
Guaranteed savings contract	The initial stage of the energy-saving renovation project will be funded by the ESCOs, and the client does not need to invest any money.	After both parties have inspected and confirmed that the energy savings have reached the levels stipulated in the contract, the client will pay the cost for the energy-saving renovation project.	By guaranteeing the energy-saving benefits of the project, the ESCOs directly receive the contracted renovation and service fees.

3.2. Reallocating performance and O&M risks by utilizing the risk transfer matrix

The Debt Aversion and Limited Rationality of business owners are the main motivations that hinder the adoption of power storage systems. The EaaS model, starting from both performance and operation maintenance aspects, has constructed a risk transfer matrix:

The EaaS model mandates that Energy Service Companies (ESCOs) bear all the performance risks during the project operation period, rather than the property owners. The losses caused by poor equipment performance or equipment failures are fully borne by the energy service companies, and the profits are directly linked to the actual power generation or peak-valley difference electricity volume [11].

ESCOs, leveraging its profound industry expertise, digital operation platform and operational resources provided by a professional technical team, effectively address the concerns of the owners regarding the shortcomings in post-construction operation and maintenance [8]. Taking the empirical analysis of a project in Beijing by Chang Hai as an example, the professional team conducted multiple simulation exercises, and the efficiency of fault handling was improved by more than 60% compared to traditional operation and maintenance [5].

3.3. "Value co-creation" network of multiple parties engagement

Value Co-creation is manifested in the EaaS model, where value is jointly created by multiple actors (Axiom 2). The owner provides idle rooftop space and real power generation data (objective resources), transforming from a passive energy consumer to an active "Prosumer" and data provider. They collaborated with the ESCOs to provide reliable Operational Resources, jointly facilitating the implementation of commercial and industrial PV-plus-storage projects and achieving value creation [8].

4. Evidence and reflection

4.1. Empirical evidence in the chinese market

According to the authoritative data released by EMCA, by the end of 2023, the total output value of China's energy conservation service industry reached 520.2 billion RMB, and the new investment in energy contract management projects amounted to 164.7 billion RMB. Distributed photovoltaic power generation remains a major market trend, and the number of energy cost management type (i.e., Energy cost hosting scheme) projects has been increasing rapidly [12]. Market preferences were further strengthened in 2024. The 2024 China Energy Conservation Service Industry Development Report shows that the total output value of China's energy conservation services has risen to 528.003 billion RMB, and the investment in energy contract management projects has reached a record high of 170.23 billion RMB. At the same time, energy cost management projects accounted for nearly 40% of the total market share, and the "Shared savings contract" accounted for 31.6% [13]. The forecast by Future Market Insights further confirmed that the EaaS market in China will continue to expand at a compound annual growth rate of 11.3% until 2035 [14].

4.2. Insufficient research and future challenges

The data shows that the willingness of C&I owners to install PV-plus-storage systems is increasing. However, the EaaS model still faces the following challenges in China: a. Long-term contracts and credit risks: The execution period of EMC contracts is usually 15-20 years. For small and medium-sized enterprises with significant fluctuations, how to assess the company's long-term viability and payment credit is the biggest difficulty in project implementation [1, 11]. b. Policy adjustments and pressure from the spot market: As the power spot market is fully implemented in 2025, the existing revenue calculation model is facing significant challenges. The risk of electricity price fluctuations is shifting from the power grid to both the supply and demand sides. This requires ESCOs to possess stronger capabilities in revenue calculation and power trading [3].

5. Conclusion

This study, through theoretical construction and empirical data, has confirmed that the EaaS model successfully overcame the "adoption paradox" among Chinese business owners. By restructuring CAPEX into OPEX, this model effectively enhanced the adoption intentions of business owners. Furthermore, this research still has certain limitations remaining. Due to the limitation of obtaining long-term data at the micro level, the study has not yet employed methods such as the Difference-in-Differences (DID) to quantitatively verify the 'net effect' of the implemented model. In the future, I will continue to conduct in-depth research and use the DID methodology to accurately assess the actual contribution of EaaS to enterprises' purchasing intentions, providing more causal inference-based empirical references.

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