

EVALUATING PUBLIC-PRIVATE PARTNERSHIPS IN ENERGY EFFICIENCY: FINANCING AND RISK ALLOCATION STRATEGIES

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ABSTRACT

The paper aims to analyze financing and risk allocation strategies in energy-efficiency Public-Private Partnerships (PPPs) and underscores that excessive financial complexities and inadequately calibrated risk transfer may potentially compromise transparency, fiscal discipline, and long-term effectiveness. The results indicate that proportional, transparent financing frameworks and balanced risk allocation are necessary conditions for achieving sustainable and credible energy-efficiency PPPs and argue that well-designed energy-efficiency PPPs can generate cumulative and mutually reinforcing benefits, including reductions in greenhouse gas emissions, lower system-wide energy costs, improved industrial competitiveness, and decreased dependence on imported energy.

KEYWORDS: *PPP, energy efficiency, risk allocation, investments, projects.*

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1. INTRODUCTION

The evaluation of public-private partnerships (PPPs) in the field of energy efficiency is multidimensional, involving institutional design, allocation of risks, financial performance, and the surrounding policy environment. PPPs represent an instrument for mobilizing capital, accelerating infrastructure development, and advancing energy-efficiency goals through market-based and contractual innovations. Energy efficiency has emerged as a significant component in contemporary energy and climate strategies, owing to its potential to curtail emissions and energy demand. Energy efficiency has emerged as a fundamental component of contemporary energy and climate policy, owing to its ability to reduce greenhouse gas emissions, moderate energy demand, and bolster economic resilience while constraining long-term public expenditure. A comparison of energy-efficiency measures and supply-side investments indicates that the former is widely recognized as cost-effective and socially beneficial, although energy-efficiency investments possess considerable technical and economic potential, they continue to encounter a persistent implementation gap. Among the possible key obstacles to large-scale deployment include high upfront costs, fragmented ownership structures, split incentives, and uncertainty regarding future savings.

In this context, public-private partnerships (PPPs) have gained increasing attention as policy instruments capable of mobilizing private capital and expertise in support of public energy-efficiency objectives. Governments have increasingly relied on PPPs to address budgetary constraints and enhance the efficiency and effectiveness of public investment. In the domain of energy efficiency, Public-Private Partnerships (PPPs) are often touted as mechanisms that can expedite project implementation, introduce performance-based incentives, and more efficaciously distribute risks

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between public and private entities. However, the increasing reliance on PPPs gives rise to significant policy concerns, particularly in sectors where returns are indirect and uncertain.

The configuration of financing arrangements and risk-allocation mechanisms is identified as a pivotal factor in the policy effectiveness of PPPs in the domain of energy efficiency. Energy-efficiency investments, in contrast to conventional infrastructure projects, do not yield direct revenue streams, instead, they depend on energy savings that accrue over time and are influenced by behavioral, regulatory, and technological factors which introduces complexity to the design of contracts and increases vulnerability to performance risk.

Empirical research has highlighted the potential and limitations of PPPs in addressing these challenges. Shao et al. (2021) demonstrate that the implementation of mechanisms for the identification and monitoring of risk in the early stages of PPP (Public-Private Partnership) projects can result in a significant reduction in uncertainty, thereby improving investor confidence and project resilience. Chen (2021) utilizes stochastic frontier analysis, a quantitative approach, to ascertain that Public-Private Partnership (PPP) infrastructure projects often exhibit higher input-output efficiency compared to traditionally procured projects, thereby signifying the potential of PPPs to enhance fiscal and operational performance under conducive conditions. While these studies offer valuable insights, they do not adequately address the interaction between financing structures and risk allocation, on the one hand, and the specific economic characteristics of energy-efficiency investments, on the other. Concurrently, critical scholarship posits that PPPs have the potential to obfuscate accountability, diminish democratic oversight, and engender contingent fiscal liabilities, particularly when contractual arrangements are intricate and protracted. In the context of energy-efficiency projects, where the verification of performance outcomes is challenging to anticipate, these risks are particularly salient. In a broader macroeconomic context, Nsouli (2022) argues that, when embedded within robust institutional frameworks and sound public finance practices, PPPs have the potential to contribute to alleviating infrastructure gaps and reducing fiscal pressures, particularly in low- and middle-income countries.

The paper undertakes an in-depth analysis of public-private partnerships (PPPs) in the field of energy efficiency, with a specific focus on the linkages between funding methods and risk-allocation mechanisms. Energy efficiency is a widely accepted approach for meeting environmental and economic goals; nonetheless, investment levels remain insufficient. PPPs are widely marketed as solutions to this gap, but the paper argues that their design frequently becomes mismatched with the special economic characteristics of energy-efficiency projects. The study concludes that energy-efficiency PPPs should be evaluated based on their ability to deliver long-term energy savings through proportionate, transparent financing and balanced risk-sharing arrangements embedded in strong institutional frameworks, rather than their ability to raise private capital.

2. LITERATURE REVIEW

Energy efficiency is widely recognized in both academic and policy literature as a cost-effective and strategically robust response to the intertwined challenges of climate change mitigation, energy security, and long-term economic sustainability. Within this context, public-private partnerships (PPPs) have emerged as a central governance and financing mechanism for delivering energy-efficiency investments. Prior research emphasizes the importance of strategic alignment and governance quality in PPP performance. Shulyk (2022) demonstrates that aligning PPP projects with national and local development strategies significantly enhances their effectiveness by embedding financing and risk-sharing arrangements within broader socio-economic objectives. Institutional capacity, regulatory stability, and stakeholder engagement further shape PPP outcomes, as evidenced in studies of power-sector PPPs in Ghana and ASEAN countries, where coherent policy frameworks and political leadership are shown to be critical for achieving sustainable energy goals (Kukah et al., 2023; Hossin et al., 2024).

Risk allocation and performance management constitute a second major research stream. Ghorbany et al. (2024) propose a performance management framework based on Copula Bayesian Networks, illustrating how causal interactions among key performance indicators and risk factors influence PPP outcomes. Complementary analytical models focus on optimizing the distribution of risks and rewards between public and private partners, thereby supporting long-term contractual stability and off-balance-sheet financing for public authorities (Martiniello et al., 2020).

At the project level, considerable attention has been devoted to contractual and financial design, particularly in energy performance contracting (EPC). Carbonara et al. (2018) employ a net present value (NPV) framework to compare alternative EPC configurations, identifying contractual arrangements that maximize joint value creation while aligning private profitability with public energy and cost savings. Similar insights emerge from studies on infrastructure modernization, such as combined heat and power (CHP) plants, where blending public funding with private capital enables large-scale technological upgrades under fiscal constraints (Nikonova et al., 2019).

An expanding body of literature situates energy-efficiency PPPs within broader green finance and clean energy transitions. Sule et al. (2024) argue that targeted policy support and international cooperation are necessary to overcome structural barriers to green investment, with PPPs serving as an effective channel for mobilizing green finance. Insights from adjacent clean energy sectors, such as hydrogen supply chains, underscore the need for flexible financing instruments and adaptive risk-sharing arrangements in contexts characterized by technological uncertainty and market volatility (Harichandan & Kar, 2025).

The regulatory and incentive environment further conditions PPP effectiveness. Studies show that clear legal frameworks and well-designed subsidy schemes are crucial for aligning private incentives with public objectives, while poorly calibrated support mechanisms may distort market signals (Huang et al., 2021; Khawaja et al., 2021). Strong environmental regulation has also been found to enhance the effectiveness of government support and improve operational efficiency in energy-related PPPs (Shen et al., 2024). PPPs are increasingly analyzed as instruments of environmental policy rather than solely as project delivery mechanisms. Empirical evidence from China indicates that PPPs, when combined with technological innovation and green finance, contribute to carbon emissions reduction and environmental performance improvement (Cheng et al., 2021; Zhang, 2024). Recent studies further extend this perspective by highlighting the emergence of Public–Private–Community Partnerships (PPCPs), which embed energy projects within their social and environmental contexts and thereby enhance legitimacy and policy effectiveness (Emia et al., 2024).

3. FINANCING MECHANISMS FOR ENERGY-EFFICIENCY PUBLIC–PRIVATE PARTNERSHIPS

Financing methods are frequently identified as a significant benefit of public–private partnerships (PPPs) in energy-efficiency projects, particularly in addressing the persistent underinvestment in public sectors such as healthcare and facilitating the expeditious implementation of efficiency measures. The combination of public support, private capital, and expertise has led to the portrayal of PPPs as flexible instruments capable of overcoming budgetary constraints. However, this optimistic narrative frequently understates the structural limitations and unintended consequences embedded in the financial architecture of energy-efficiency PPPs.

Energy-efficiency investments differ fundamentally from conventional infrastructure projects due these systems generally necessitate substantial initial capital expenditures, with the primary source of return derived from the avoidance of energy expenditures rather than direct revenue generation, benefits which are realized over time and are subject to uncertainty due to behavioral factors, energy price volatility, and technological performance as remarked by (Carbonara, & Pellegrino, 2018) and Hou, et al., (2025)

Conventionally, public authorities have addressed these constraints through regulatory measures, fiscal incentives, and direct public investment. In this policy context, PPPs have emerged as hybrid governance and financing mechanisms intended to mobilize private resources while maintaining public oversight and alignment with policy objectives. In the context of energy efficiency, Public-Private Partnerships (PPPs) are devised to address market failures stemming from information asymmetries and positive externalities.

In the context of energy-efficiency Public-Private Partnerships (PPPs), public finance customarily assumes a catalytic function. Instruments such as grants, tax incentives, concessional loans, and public guarantees are employed to mitigate perceived project risks and enhance bankability, tools that are indicative of the recognition that private markets frequently underinvest in energy efficiency due to a lack of full internalization of social and environmental benefits.

Private funding is typically provided by energy service companies, commercial banks, and institutional investors. As Hodge & Greve, (2017) argues these entities contribute capital, as well as technical expertise and operational capacity. Their involvement is frequently structured through performance-based contracts, in which remuneration is linked to verified energy savings. While such arrangements seek to align financial incentives with technical outcomes and long-term performance, they concomitantly engender increased contractual and methodological complexity, particularly with regard to the measurement and verification of savings.

Blended-finance structures have become increasingly prominent in energy-efficiency PPPs as a means of managing heterogeneous risk profiles due the fact that these arrangements integrate senior private debt with subordinated public funding and risk-sharing instruments, including guarantees. While blended finance has the potential to enhance financial viability and attract private capital, it also introduces increased transaction costs and necessitates sophisticated financial and administrative capabilities. Given that a considerable number of energy-efficiency projects are of modest or intermediate scale, the proportionality and cost-effectiveness of such complex structures are often subject to scrutiny as highlighted by Du et al., 2028

The temporal discrepancy between the initial investment costs and the subsequent long-term benefits further influences financing decisions. The utilization of long-term financing instruments and extended contractual durations is imperative to ensure that debt servicing is aligned with the realized energy savings. The reliance on extended time horizons renders projects particularly sensitive to policy and regulatory stability and the changes in energy prices, subsidy regimes, or efficiency standards can significantly affect financial projections and investor confidence.

Consequently, evaluating the efficacy of financing mechanisms in energy-efficiency PPPs necessitates an assessment that extends beyond the mere measurement of their capacity to mobilize private capital. Financial leverage is a means to an end, not an end in itself. The pivotal criterion is whether PPP financing delivers energy savings at lower lifecycle costs and with greater reliability than alternative public or private delivery models. The extant literature indicates that financing arrangements that are simpler and more transparent frequently exhibit superior performance in comparison to those that are highly complex, particularly within institutional settings characterized by limited administrative capacity.

Two structural criticisms are particularly salient as Krumm, (2016), Wang et al., (2025) and Andonova (2025). Firstly, private capital is inherently more costly than public borrowing due to risk premiums, profit expectations, and transaction costs. In the context of energy-efficiency initiatives, where the returns are indirect and uncertain, a significant reliance on private financing can compromise the economic rationale underlying efficiency improvements. Secondly, the increasing intricacy of financing mechanisms, characterized by layered instruments, blended finance, and performance-linked repayments, has the effect of reducing transparency and complicating public oversight. In the context of relatively modest-scale projects, the financial complexity may prove to be a source of inefficiency rather than a solution, given that administrative and transaction costs may exceed the anticipated efficiency gains.

4. IMPLICATIONS FOR PROJECT PERFORMANCE AND SUSTAINABILITY

The performance and long-term sustainability of energy-efficiency projects implemented through public–private partnerships (PPPs) are fundamentally determined by the interaction between financing arrangements and risk allocation strategies. Conventional infrastructure projects are characterized by tangible outputs and the capacity to verify performance through physical delivery. In contrast, energy-efficiency Public-Private Partnerships (PPPs) depend on the realization of energy savings over time. The aforesaid savings are inherently uncertain due to the fact that they are influenced by technical performance, user behavior, and external economic conditions.

Financing structures play a pivotal role in shaping incentives and determining fiscal exposure and on this reasoning a greater reliance on private capital is often associated with stronger performance incentives for private partners, particularly in performance-based financing models where remuneration is linked to verified energy savings as in (De Marco et al., 2016; Lu et al., 2022). Such organizational arrangements have the potential to enhance operational efficiency and promote technical optimization and the reliance on projected savings as the foundation for financial viability introduces a significant performance risk. Assumptions regarding energy prices, consumption patterns, and technological performance that are overly optimistic in nature have the potential to undermine expected returns and compromise project stability. The transfer of a disproportionate amount of performance risk to private partners has the potential to hinder market participation or lead to conservative project design.

Risk allocation strategies have been shown to influence project outcomes by defining responsibilities and accountability within the partnership. The allocation of technical and operational risks to private partners is consistent with the principle that risks should be borne by the actors best positioned to manage them. This alignment has the potential to facilitate enhanced lifecycle management and optimize outcomes and the efficacy of measures is contingent upon the robustness of the performance measurement and verification systems. Accurate and transparent monitoring of energy savings is imperative to ensure the effective functioning of contractual incentives. Inadequate measurement frameworks can give rise to disagreements concerning realized savings, erode trust between partners, and eventually compromise project performance. Therefore, performance monitoring should be conceptualized as a fundamental governance mechanism rather than a purely technical requirement. The concept of sustainability in energy-efficiency Public-Private Partnerships (PPPs) encompasses not only immediate operational performance but also extends to the financial, institutional, environmental, and social dimensions as (Balcilar et al., 2025 and Gorodnova, (2023) and achieving financial sustainability necessitates the establishment of stable financing structures and realistic risk-sharing arrangements. Such arrangements are essential in minimizing the likelihood of recurrent renegotiations or hidden fiscal burdens. In this regard, the predictability of regulatory and policy environments is paramount, as alterations in energy pricing, subsidy schemes, or efficiency standards can substantially impact project economics and disrupt meticulously calibrated risk allocations.

The capacity of public authorities to design, manage, and oversee complex PPP contracts is a critical factor in ensuring institutional sustainability. Energy-efficiency projects are often initiated at the local or municipal level, where administrative and technical resources may be constrained. Adequate oversight is imperative for the effective enforcement of performance standards and the preservation of the credibility of contractual commitments. As time progresses, there is the possibility that a series of occurrences of underperformance or contractual disputes may result in the erosion of institutional confidence in PPPs as a policy instrument.

The primary policy rationale for energy-efficiency PPPs is environmental sustainability; however, this is not guaranteed by project implementation alone. In the event that financing and risk allocation arrangements prioritize short-term financial returns, projects may prioritize incremental or easily achievable savings rather than deep, long-term efficiency improvements. It is imperative to align financial incentives with long-term environmental objectives. One method of doing so is through the

implementation of contractual mechanisms that offer incentives for continuous performance enhancement and penalties for performance degradation over time. A closely related issue is that of scalability and replicability and the projects distinguished by transparent financing, balanced risk allocation, and stable performance are more likely to be replicated across sectors and jurisdictions, thereby amplifying their policy impact.

The nexus between financing and risk allocation carries significant ramifications for public legitimacy and stakeholder acceptance. Energy-efficiency Public-Private Partnerships (PPPs) frequently function within public buildings and services, exerting a direct influence on citizens. Public opposition to energy projects can result from perceived imbalances in risk sharing or opaque financing arrangements, even when projects demonstrate quantifiable efficiency gains. In particular, the utilization of guarantees and other risk-mitigation instruments has the potential to generate contingent liabilities that are not fully apparent at the project's inception and it can lead to an inaccurate perception of risk transfer. Such dynamics give rise to concerns regarding fiscal responsibility and distributive equity, as private gains may be secured while losses are ultimately borne by the public sector.

The effectiveness and long-term viability of public-private partnerships (PPPs) in the energy efficiency sector are contingent on the synergistic interplay of design choices pertaining to financial mechanisms and risk allocation methodologies and when these elements are coherently aligned, PPPs have the potential to deliver durable economic and environmental benefits and support broader energy-transition objectives and in the event of misalignment, there exists the possibility of substandard performance, financial instability, and a reduction in policy credibility.

5. CONCLUSIONS

This study has critically examined public-private partnerships (PPPs) in the domain of energy efficiency, with particular attention to the interdependence between financing mechanisms and risk allocation strategies. Energy-efficiency investments differ fundamentally from traditional infrastructure projects in that they rely on indirect and uncertain returns derived from future energy savings rather than direct revenue generation and the structural characteristic renders both financial design and contractual risk sharing especially sensitive and underscores the need for cautious, proportionate, and well-governed PPP arrangements.

The analysis indicates that financing structures play a decisive role in shaping incentives, fiscal exposure, and long-term project outcomes. While private participation can introduce managerial expertise, technological capability, and performance-oriented discipline, private finance is intrinsically more costly than public borrowing and often accompanied by increased transaction and administrative complexity. In energy-efficiency PPPs, the growing reliance on blended finance, guarantees, and layered contractual arrangements may create an appearance of risk transfer while, in practice, exposing the public sector to contingent liabilities that are difficult to detect *ex ante*. When such mechanisms are applied without due proportionality, particularly in relatively small-scale projects, they risk undermining transparency, accountability, and overall economic efficiency.

The principle that risks should be allocated to the actors best positioned to manage them remains valid, especially with respect to technical and operational risks borne by private partners. However, this principle is effective only when supported by credible, transparent, and enforceable systems for measuring and verifying energy savings. Weak monitoring frameworks and overly optimistic assumptions regarding future performance can lead to contractual disputes, renegotiations, and the gradual re-socialization of risk, thereby eroding both investor confidence and public trust. Balanced and realistic risk-sharing arrangements are therefore essential to sustain participation on both sides of the partnership. From a broader policy perspective, the findings suggest that the evaluation of energy-efficiency PPPs must extend beyond the narrow objective of mobilizing private capital. Financial

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