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Scale-Dependent Financial Viability of Energy Plus Service Models: A Monte Carlo Analysis of Residential Retrofit Projects Under Uncertainty

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Abstract

Decarbonising the residential building sector requires not only technical solutions, but also financially viable delivery models. This paper examines the economic performance of Energy Plus Service (EPS) schemes applied to deep renovation projects under uncertainty, with particular attention to the role of project scale and market conditions. The analysis is based on a portfolio of 21 residential buildings in Northern Italy and combines a Discounted Cash Flow (DCF) model with Monte Carlo simulation. Key sources of uncertainty include renovation costs, post-retrofit energy performance, rental values, and electricity prices, allowing for the estimation of probabilistic Net Present Value (NPV) outcomes. The results show a clear impact of residential asset spatial scale on financial outcomes. Small projects are generally unprofitable, while medium-sized assets are highly sensitive to uncertainty. Larger projects, instead, display a much higher likelihood of positive financial outcomes. Sensitivity analysis indicates that financial performance is driven mainly by investment costs and rental income, while energy-related variables play a more limited role. The findings suggest that the viability of EPS models depends as much on market conditions as on technical performance, pointing to a potential misalignment between energy policy objectives and private investment incentives. Results suggest that projects approaching 160 m^2 are more likely to achieve a 50% probability of a positive NPV, indicating a potential scale threshold beyond which EPS schemes become significantly more bankable and below which aggregation or additional de-risking measures are likely to be required.

Keywords: energy efficiency; Energy Plus Service (EPS); building retrofit; Monte Carlo simulation; Net Present Value (NPV); risk analysis; real estate market; building decarbonisation

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1. Introduction

Over the past decades, the relationship between energy efficiency in real estate and economic performance has gained increasing attention in both academic research and policy agendas. The Paris Agreement and the European Green Deal have accelerated the promotion of several reforms aimed at improving the energy efficiency of the building stock [1–3].

The Energy Performance of Buildings Directive (EPBD IV—Green Homes) has set even more ambitious targets for building efficiency in the European real estate context [4–6]. Within this evolving regulatory landscape, increasing attention has been devoted to inte-

grated sustainable service-based models designed to overcome the structural barriers that hinder deep energy renovation in the residential sector [7,8].

The EPS model, together with its predecessor Energy Performance Contracting, can be theoretically framed as a Product–Service System (PSS), a category of business models where the focus shifts from selling physical products to providing integrated solutions that satisfy specific customer needs. According to the classification by Tukker (2004), the EPS aligns with result-oriented services, where the provider maintains ownership of the assets and the user pays for a guaranteed level of performance [9].

A growing body of literature has explored the relationship between energy efficiency and real estate values, as well as the operational characteristics of EPC schemes. Empirical evidence generally confirms a positive relationship between higher energy performance and real estate value on property values and market perception, while sustainability considerations increasingly influence investment decisions and risk assessment practices. However, existing studies tend to analyse either market outcomes or simplified financial structures, without fully capturing the complexity of service-based renovation models [10–13].

Limited attention has been devoted to the joint evaluation of energy performance, contractual arrangements and financial feasibility within a unified analytical framework. This gap is particularly relevant given the high level of uncertainty affecting long-term renovation investments, including variability in costs, revenues and behavioural factors [14].

The Energy Performance Contracting (EPC) model represents a performance-based contractual framework in which energy efficiency interventions are financed and implemented through long-term agreements [4,15,16]. Within this structure, Energy Service Companies (ESCos) assume a central role, being responsible for the design, implementation and monitoring of interventions, while bearing both financial and performance risks. Revenues are typically linked to the energy savings achieved, aligning economic returns with actual performance outcomes. In most EPC arrangements, the client continues to pay the utility bills, whereas the ESCo is repaid through an agreed share of the verified savings, with the allocation of payment and performance risk depending on the specific contract type. Clients benefit from reduced energy costs without upfront investments, while financial institutions and technical experts support project implementation and validation [17–19] (Figure 1).

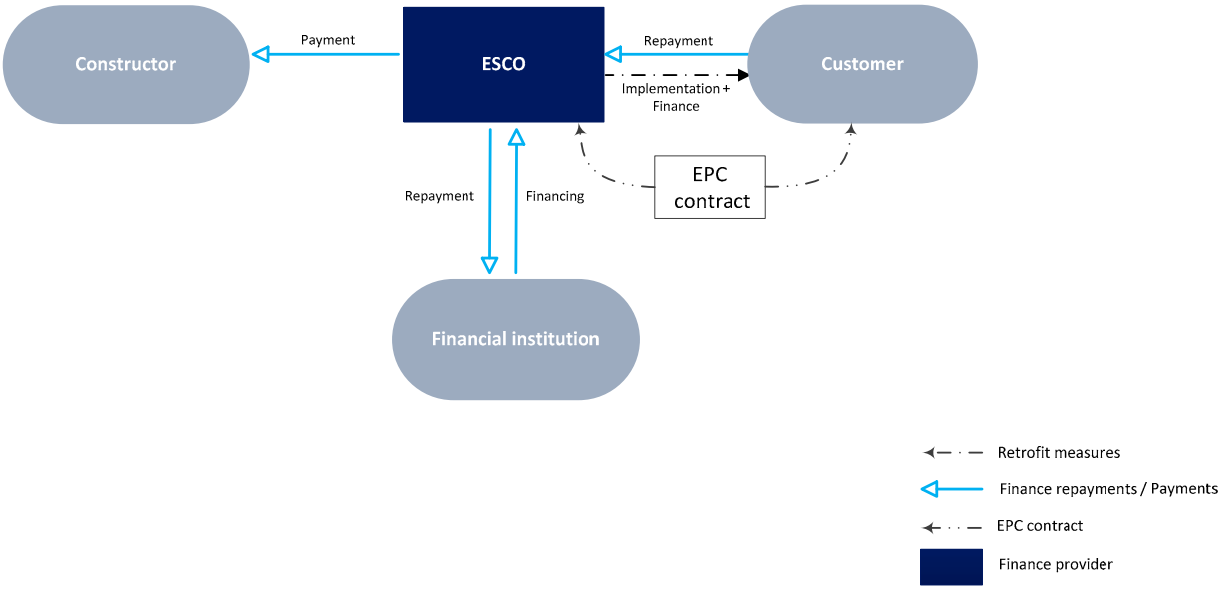


Figure 1. EPC Business Model scheme.

The Energy Plus Service (EPS) model can be considered an evolution of the EPC and it can be situated within the broader family of service-based business models for retrofit delivery. Conceptually, it shares several features with other integrated approaches such as Managed Energy Service Agreements (MESAs) and contractor-managed investment (CMI) models, in that all three seek to bundle technical measures, financing and service provision into a single contractual framework.

In line with MESA-type arrangements, EPS shifts the focus from isolated works to long-term service performance, with the service provider recovering its investment through recurring fees rather than one-off construction margins [20–22]. Compared to CMI-type models, where contractors often manage investment on behalf of the owner while the energy supply relationship remains largely unchanged, EPS more explicitly internalises the energy provision dimension, with the ESCo acting as the contractual interface between energy suppliers and tenants [23,24].

While maintaining a similar set of actors, EPS redefines both operational responsibilities and revenue mechanisms [24]. In this configuration, the ESCo not only implements efficiency measures as in conventional EPC models but also acts as an energy intermediary: it procures electricity and other energy carriers from an external energy provider and resells them directly to the end-users under a bundled service fee. The physical retrofit works are carried out by construction contractors engaged and coordinated by the ESCo, whereas the energy provider's role is limited to supplying energy to the ESCo rather than directly to the end-users. The energy provider and the ESCo therefore remain two distinct parties, with the ESCo assuming the role of contractual interface and service integrator for the tenants [24,25]. This results in a more integrated and service-oriented model, in which the ESCo coordinates the entire value chain, including relationships with energy providers. In the EPS model, by contrast, the ESCo becomes the main contractual counterpart for tenants, integrating investment, operation and energy provision into a single service contract (Figure 2).

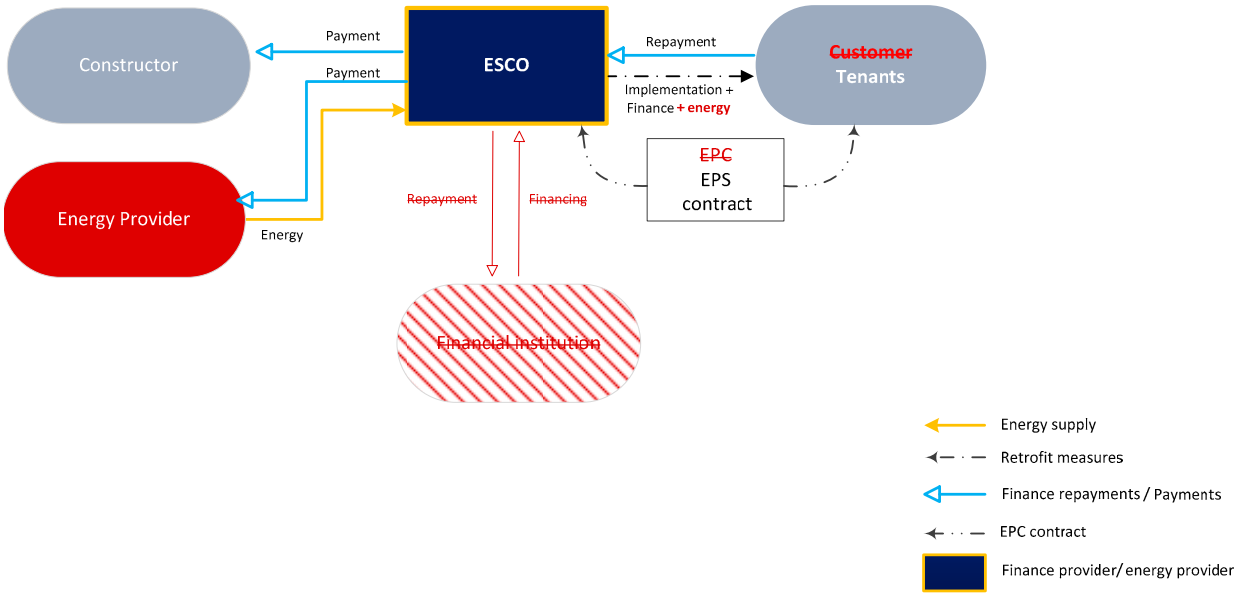


Figure 2. EPS Business Model scheme (Red strikethroughs highlight the components and interactions that are modified or replaced in the innovative configuration).

Beyond the technical configuration of the two models, Figures 1 and 2 also embody a fundamentally different allocation of financial risk. In the traditional EPC setting (Figure 1), the ESCo and the financial institution jointly absorb a substantial share of the investment

and performance risk, while households mainly experience a reduction in energy bills without directly taking on long-term debt. In the EPS configuration (Figure 2), by contrast, tenants and homeowners are more explicitly exposed to credit and cash-flow risk, as their service fees must cover both capital recovery and operating costs under uncertain market conditions. This shift in risk allocation helps explain why households and small landlords may resist EPS-type arrangements, and why financial institutions adopt conservative criteria when evaluating these projects.

In this context, the present study provides insight into how a financial institution might assess EPS projects, by quantifying the distribution of possible outcomes rather than relying on single-point estimates. By examining not only expected NPV but also the upper and lower bounds of the simulated distributions and the probability of loss, the analysis mirrors the risk-based reasoning that underpins real investment decisions. It contributes to this debate by analysing the application of the EPS model to a portfolio of 21 residential buildings located in the Veneto region (Northern Italy). The analysis adopts the perspective of the service provider and combines deterministic financial evaluation with a probabilistic simulation framework, explicitly accounting for uncertainty and risk distribution over different time horizons. By integrating real market data, project finance indicators and stochastic modelling techniques, the study evaluates both the economic feasibility and the robustness of the EPS model under alternative scenarios. In this context, the analysis is guided by the following research questions:

- **RQ1:** To what extent is the EPS model economically viable under different assumptions on costs, revenues and incentives when uncertainty is explicitly considered?
- **RQ2:** Which variables most significantly influence financial performance and risk distribution across heterogeneous projects?
- **RQ3:** How do changes in key parameters affect the robustness and scalability of integrated energy service models?

Construction cost uncertainty remains particularly relevant in the Italian context, where recent policy measures such as the Superbonus have introduced significant market volatility.

The remainder of the paper is structured as follows. Section 2 presents the materials and methods, including the EPS framework, the dataset and the Monte Carlo (MC) simulation approach. Section 3 discusses the results, Section 4 presents and discusses the results whereas Section 5 presents the main conclusions and implications of the study.

2. Materials and Methods

2.1. Study Area and Dataset

This study draws on a dataset of 21 residential buildings located in the provinces of Treviso, Pordenone, and Venice (Veneto and Friuli-Venezia Giulia regions, Northern Italy) (Figure 3).

The portfolio includes both detached single-family houses and multi-unit residential complexes, all of which underwent deep energy retrofits under a service-based contractual arrangement. The dataset was provided by NIDA Architetti (Treviso, Italy), which collected and systematised the technical and economic information on the projects. The geographic concentration of the sample ensures homogeneity with respect to the applicable building regulations, climate zone classification (Zone E, under Italian standards), and local real estate market dynamics.

For each building, the dataset initially records a unique case study identifier (CS_01 to CS_21), geographic coordinates (city, latitude, longitude), building typology (BT) and net floor area (NFA), visible in Table 1.

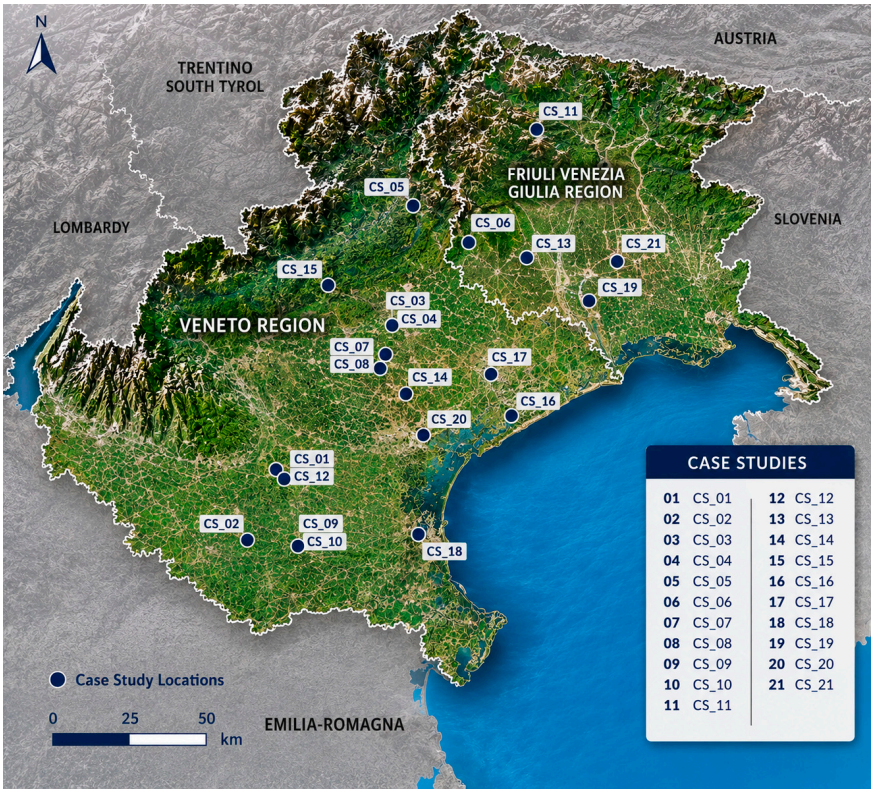


Figure 3. Location of the 21 case studies in the Veneto and Friuli-Venezia Giulia regions (Northern Italy). Case study data provided by NIDA Architetti (Treviso, Italy).

Table 1. Case study characteristics.

Case Study	NFA (m^2)	BT	City
CS_01	221.34	detached house	Casier (TV)
CS_02	211.52	detached house	Cadoneghe (PD)
CS_03	150.57	detached house	Treviso
CS_04	212.15	detached house	Treviso
CS_05	171.66	detached house	Vazzola (TV)
CS_06	172.97	detached house	Mansuè (TV)
CS_07	111.61	semi-detached house	Spresiano (TV)
CS_08	51.51	semi-detached house	Spresiano (TV)
CS_09	119.48	terraced house	Scorzè (VE)
CS_10	116.71	terraced house	Scorzè (VE)
CS_11	180.44	terraced house	Porcia (PN)
CS_12	171.89	detached house	Casier (TV)
CS_13	135.17	detached house	Maserada sul Piave (TV)
CS_14	170.16	detached house	Silea (TV)
CS_15	268.21	detached house	Spresiano (TV)
CS_16	118.51	terraced house	Oderzo (TV)
CS_17	141.97	detached house	Preganziol (TV)
CS_18	154.13	detached house	Silea (TV)
CS_19	153.84	detached house	Pasiano di Pordenone (PN)
CS_20	122.36	terraced house	Silea (TV)
CS_21	66.87	detached house	Pordenone (PN)

The Net Present Value (NPV) of the EPS contract is calculated as follows:

$$\mathrm{NPV} = -\mathrm{I}_0 + \sum_{\mathrm{t}=1}^{\mathrm{T}} \frac{CF_t}{(1+\mathrm{r})^{\mathrm{t}}} = -\mathrm{I}_0 + \sum_{\mathrm{t}=1}^{\mathrm{T}} \frac{\mathrm{R}_0(1+\mathrm{g})^{\mathrm{t}-1} + \mathrm{E}_0(1+\mathrm{g})^{\mathrm{t}-1}}{(1+\mathrm{r})^{\mathrm{t}}} \quad (1)$$

where

- NPV—Net Present Value: the total value of the project expressed in today's terms, accounting for the time value of money.
- I_0—Initial Investment (Investment Costs): the upfront capital expenditure made at the start of the project (time zero).
- CF_t—Net Cash Flow in Period t: the difference between cash inflows and outflows in a given year; what the project actually generates or costs in each period. It is obtained by combining the time-evolving rental and energy-service revenues (derived from R_0 and E_0).
- R_0—Net Rent Revenue: the net rental income earned in the first period, after deduction of the corresponding operating costs, which serves as the base figure before any growth is applied.
- E_0—Net Revenues from Energy Services: the net income generated by the energy service component in the first period, after deduction of the corresponding operating costs, also used as a base before growth.
- g—Growth Rate: the annual rate at which revenues grow over time. A positive value means revenues increase each year.
- r—Discount Rate: the required rate of return, or cost of capital, used to convert future cash flows into their present value equivalent.
- t—Time Period: an index representing a specific year within the project lifetime.
- T—Project Horizon: the total number of years over which the project is evaluated. In the case of the EPS project, this is capped at 10 years from the completion of the renovation works, as this represents the maximum allowable payback period.

In practice, CF_t aggregates, for each year t, the net rental income and the net revenues from energy services, starting from the first-year values R_0 and E_0 and applying the assumed growth rate g over the 10-year contractual horizon.

Table 2 provides an energetic and economical description of the renovation projects. It presents the energy performance index before and after retrofit (CE_prior and CE_post, kWh/m^2/year) and a breakdown of total investment (€) into renovation works (Cost_renov_works), professional fees (Prof_fees), and tax expenditures (Tax_exped), and finally the prevailing rental values (€/m^2/month).

Energy performance data were originally recorded as categorical EPC labels on the Italian national scale (from G, worst, to A4, best). Prior to simulation, these labels were converted to continuous numerical EPIa values (kWh/m^2/year) using the class midpoint thresholds established under the Ministerial Decree of 26 June 2015 [26]. This recoding step was required to comply with Oracle Crystal Ball's constraint that all stochastic inputs be expressed as continuous numerical variables; the full conversion table is provided in Table A1 (Appendix A). For the lower-performing classes (specifically class G), the value of 450 kWh/m^2/year was adopted as a conservative representative proxy for non-renovated buildings in Climate Zone E, consistent with national technical standards and regional building stock statistics. This approach ensures that the stochastic input distribution reflects realistic physical performances while maintaining compliance with the categorical constraints of the original dataset.

Rental values were drawn from the Italian Revenue Agency's Real Estate Market Observatory (OMI) database, adopting the upper bound of the "excellent condition" band—a classification consistent with the post-retrofit energy performance of the portfolio, the majority of which reaches EPC class A or above. Costs of maintaining and managing the property after the renovation have been introduced to obtain the net rental value, based on a summary estimate drawn from the real estate literature [27–29]. In the DCF model, all case studies are treated as rental properties, and these net rental values enter as annual

cash inflows over the contractual horizon. The economic benefit of the retrofit is therefore assessed by comparing the NPV of post-intervention net rental and energy-service revenues with the initial investment and operating costs, rather than by considering only a simple payback based on the rent increase. At the same time, energy costs were estimated separately by multiplying the post-intervention EPI by the average electricity tariff and the net floor area, to capture the operating costs borne by the ESCo within the Energy Plus Service model. Inflation rate has been established at 1,91% as indicated by estimates of future inflation in Italy.

Table 2. Renovation energy and cost data.

Case Study	CE_Prior (kWhm^2)	CE_Post (kWhm^2)	Cost_Renov _Works (€)	Prof_Fees (€)	Tax_Exped (€)	Total_Invest (€)	Rental Values (€/m^2 per Month)
CS_01	110	45	60,869.87	9080.84	9796.33	79,747.04	6.30
CS_02	195	90	63,846.10	14,544.10	9584.31	87,974.51	5.70
CS_03	350	45	150,350.48	25,381.54	23,442.42	199,174.43	8.40
CS_04	260	165	88,147.93	18,103.48	12,797.56	119,048.96	6.30
CS_05	450	260	81,723.89	14,073.06	12,862.05	108,659.00	3.60
CS_06	195	65	57,969.16	11,037.24	9837.42	78,843.81	4.30
CS_07	350	65	74,181.28	15,335.76	11,435.01	100,952.04	5.80
CS_08	450	45	63,883.89	12,854.05	10,515.66	87,253.60	5.80
CS_09	165	45	30,304.43	8048.63	5208.80	43,561.85	6.50
CS_10	165	45	31,525.01	8250.00	5305.15	45,080.16	6.50
CS_11	260	165	43,357.15	8471.12	7336.96	59,165.22	3.00
CS_12	195	110	100,830.13	22,870.95	17,905.98	141,607.05	6.30
CS_13	165	65	79,757.41	13,720.05	12,210.20	105,687.66	5.60
CS_14	350	45	108,236.82	23,387.17	17,972.86	149,596.85	5.10
CS_15	450	45	130,918.48	18,828.64	17,234.15	166,981.27	6.10
CS_16	450	110	77,777.12	18,369.69	13,337.61	109,484.42	10.00
CS_17	450	45	135,139.75	25,446.39	23,069.80	183,655.94	4.90
CS_18	195	45	104,862.31	22,335.40	18,762.02	145,959.74	5.80
CS_19	260	110	87,650.37	16,695.07	12,437.95	116,783.39	3.70
CS_20	350	110	83,475.32	17,268.89	13,860.81	114,605.02	6.30
CS_21	195	110	58,786.32	14,228.64	10,458.84	83,473.79	4.50

Finally, Table 3 summarises the main descriptive statistics of the economic variables recorded in Table 2.

Table 3. Descriptive statistics of economic variables.

Descriptive Statistics	Cost_Renov _Works (€)	Prof_Fees (€)	Tax_Exped (€)	Total_Invest (€)	Rental Values (€/m^2 per Month)
Average	81,599.68	16,110.99	13,112.95	110,823.61	5.74
Standard deviation	32,047.54	5549.88	5054.47	42,146.44	1.56
Minimum	30,304.43	8048.63	5208.80	43,561.85	3.00
Maximum	150,350.48	25,446.39	23,442.42	199,174.43	10.00

2.2. Monte Carlo and Probabilistic Simulation Framework

Economic assessments of energy service contracts are inherently subject to uncertainty across several dimensions, including construction cost variability, energy market fluctuations, and rental income sensitivity. Deterministic approaches, while adequate for point-estimate benchmarking, cannot capture the full distributional range of feasible financial outcomes.

To overcome this limitation, a Monte Carlo Simulation (MCS) approach was adopted and implemented via Oracle Crystal Ball (version 11.1.2.4.850 - Oracle Corporation)—a commercially available stochastic modelling add-in for spreadsheet environments.

The main purpose of this method is to calculate the likelihood of various outcomes in processes involving random variables. To achieve more accurate estimates of system developments, it simulates specific variables using predefined probability distributions [30–34]. There are three primary stages to the analytical process:

- Random number generation: to simulate situations that represent the model's uncertainty, random numbers are created in accordance with a probability distribution. This stage also examines how uncertainty affects the outcomes.
- Estimation of the expected mean: gives a central estimate of a random variable that reflects a complicated model's most likely result. It is equivalent to the mean of the outcomes of several simulations, all of which consider the uncertainties related to the system's parameters.
- Uncertainty assessment: measures the degree of uncertainty surrounding the model's variables and parameters, making it possible to evaluate how this uncertainty affects the outcomes.

The assessment of financial risks and opportunities from uncertain cash flows and economic projections is well-established in real estate research through MCS [32,35–39]. This approach allows for the consequences of input variability—including changes in statistical assumptions or output functions—to be evaluated with a level of detail that deterministic methods cannot achieve [40–43].

In this study, uncertain input variables are propagated through a Discounted Cash Flow (DCF) model independently calibrated for each of the 21 case studies. Each simulation runs 10,000 iterations, a sampling depth chosen to ensure stable convergence of both central moments and tail probabilities of the resulting NPV distribution. Random numbers are generated by the internal pseudo-random number generator of Oracle Crystal Ball, which samples from the specified probability distributions using independent random draws for each stochastic input. This setup ensures that the 10,000 iterations provide an unbiased approximation of the assumed input distributions and the resulting NPV outcomes. These random draws are generated from the theoretical distributions (triangular, normal, uniform and lognormal) calibrated on the empirical data, and are not obtained via bootstrap resampling of the original observations.

A uniform discount rate of 7.27%, equal to the parameter Weighted Average Cost of Capital (WACC), is applied across all projects and it is computed following the standard formulation detailed in Brealey et al. (2011) [44]. This rate is derived from cost of equity (k_e) of 12.80%—estimated via the Capital Asset Pricing Model (CAPM) using Italian sovereign bond yields, a Green and Renewable Energy sector beta [45], and an Italy-specific equity risk premium—with a cost of debt (k_d) of 4.90%, based on the average 12-month Euribor over 2022–2025 augmented by a spread derived from Bank of Italy APR statistics for long-term investment loans.

The assumed capital structure of 30% equity and 70% debt reflects financing conditions typically observed in Italian construction and infrastructure projects, where leverage is sustained by predictable long-term cash flows, the tax deductibility of interest expenses, and the relatively low risk profile attributed by lenders to asset-backed energy service arrangements [46–48]. Table 4 reports the full parameter set and sources adopted for their valuation.

Table 4. WACC Parameters and Sources.

Parameter	Source/References
Cost of Equity (K_e) $Ke = Rf + \beta x(Rm + Rf)$	• Risk free rate—average yield of 15-year Italian government bonds (MEF, 2024 series). • β—Damodaran, [45]. • Rm—Italy-specific equity risk premium.
Cost of debt (K_d) $Ke = Base\ financing\ cost + Spread$	• Base financing cost—Average 12-month Euribor over 2022–2025 • Spread—Bank of Italy APR statistics for long-term investment loans
Equity capital of the investment (E)	• 30% of the total investment [46–48].
Debt capital of the investment (D)	• 70% of the total investment [46–48].
Kd	• 4.90%
Ke	• 12.80%
WACC (calculated)	• 7.27%

2.3. Stochastic Input Variables

Four variables were identified as the principal sources of financial uncertainty and treated as stochastic inputs in the simulation. For each variable, the distributional family was selected based on the statistical properties of the empirical data and the economic rationale for the observed variability.

The parametric assumptions adopted in Crystal Ball are summarised in Table 5 and discussed individually below.

Table 5. Crystal Ball parametric variable and assumptions.

Variable	Distribution	Parameters	Rationale
Renovation works cost	Triangular	Min: €30,304 Mode: €81,600 Max: €150,350	High empirical spread (CV ≈ 39%) with asymmetric tail
Post-retrofit energy index (CE_post)	Normal	μ = 52 kWh/m^2/y σ = 35 kWh/m^2/y	Symmetric variability across building typologies
Rental value	Uniform	Min: €3.00/m^2/month Max: €10.00/m^2/month	No a priori concentration within the OMI range
Unit electricity price	Log_normal	Mean: €0.145/kWh SD: €0.027/kWh	Strictly positive, right-skewed energy price dynamics

The cost of renovation works is modelled using a triangular distribution. This choice is appropriate when available data define a plausible minimum, a most likely value, and an upper bound, but are insufficient to justify a fully parametric assumption. This approach aligns with construction market heuristics, where operators typically estimate costs in terms of minimum, maximum, and most likely values. All cost data were derived from the DEI Construction Cost Database [49]. The empirical distribution of Cost_renov_works across the 21 projects yields a minimum of €30,304, a mean of €81,600 (adopted as the modal value), and a maximum of €150,350—the latter corresponding to the highest observed renovation expenditure excluding ancillary professional fees and tax items.

The coefficient of variation of approximately 39% reflects a substantial but bounded construction cost uncertainty, consistent with the heterogeneity of building types and intervention scopes in the portfolio.

Post-retrofit energy performance index (CE_post, kWh/m^2/year) is assigned a normal distribution with mean μ = 52 kWh/m^2/year and standard deviation σ = 35 kWh/m^2/year, derived directly from the recoded empirical dataset (observed range: 20–170 kWh/m^2/year; sample SD: 34.6 kWh/m^2/year).

The normal assumption is justified by the approximately symmetric dispersion of post-retrofit performance values across heterogeneous building typologies and climatic exposures within the study area. It should be noted that the empirical distribution exhibits a degree of discretisation—an artefact of the class-midpoint conversion from categorical EPC labels—and the fitted normal distribution should therefore be interpreted as a representation of cross-project variability rather than continuous measurement uncertainty. Pre-retrofit values (CE_prior; mean: 201.4 kWh/m^2/year; SD: 103.0 kWh/m^2/year) were retained as fixed, project-specific inputs, since the ante-retrofit energy condition is an observed rather than uncertain quantity for each case study.

Rental value is treated as uniformly distributed between the minimum (€3.00/m^2/month) and maximum (€10.00/m^2/month) values recorded in the OMI dataset. The uniform distribution reflects the absence of any a priori reason to privilege a particular sub-range of the market: the study area spans both rural municipalities—where lower rental benchmarks apply—and denser urban centres with higher valuations, without a dominant concentration around any central value. OMI figures are themselves interval estimates, making a flat distributional assumption the most parsimonious choice.

Unit electricity purchase price (€/kWh) is assigned a lognormal distribution with mean €0.145/kWh and standard deviation €0.027/kWh, parametrised on the basis of a market survey conducted in May 2025 covering five major Italian electricity suppliers (A2A: €0.139/kWh; Edison: €0.111/kWh; Enel: €0.150/kWh; Plenitude: €0.186/kWh; Sorgenia: €0.140/kWh). The lognormal family is appropriate for energy price modelling given the strictly positive support and the characteristic right-skewed behaviour of wholesale electricity markets, where upward price spikes are structurally more probable than symmetric downward deviations. The fitted distribution yields a 5th–95th percentile interval of approximately €0.105–€0.193/kWh, encompassing the full range of observed market offers.

Finally, for interpretative purposes, the 21 projects are subsequently grouped into three size classes (small, medium and large), defined in terms of net floor area, as detailed later in Section 3.1.

2.4. Output Variables and Sensitivity Analysis

The primary simulation output is the Net Present Value (NPV) of the energy service contract over its contractual duration, computed within the DCF framework.

Secondary indicators, including the Internal Rate of Return (IRR) and the Discounted Payback Period (DPP), were excluded from the analysis. In the Energy Plus Service model, the maximum discounted payback period is set at 10 years from the completion of the works. In addition, the Internal Rate of Return (IRR) was excluded from the sensitivity analysis because the cash-flow structure of the EPS model did not yield a stable and economically meaningful positive return across the scenarios considered. When project cash flows remain persistently weak or close to the break-even threshold, the IRR may fail to provide a reliable indicator of profitability.

For each project, the 10,000-iteration simulation produces an empirical NPV distribution from which the following statistics are extracted: expected value E [NPV], standard deviation σ [NPV], probability of a positive outcome P [NPV > 0], and the 5th and 95th percentile bounds.

Sensitivity analysis is conducted using Crystal Ball's built-in contribution-to-variance method, based on rank correlations between each stochastic input and the NPV output.

This procedure ranks input variables by their proportional contribution to total output variance, enabling identification of the dominant uncertainty driver across the portfolio and informing targeted risk mitigation strategies.

For completeness, Table 6 reports the deterministic baseline values of NPV, IRR and Discounted Payback Period (DPP) obtained prior to the Monte Carlo simulation for each case study.

Table 6. Deterministic baseline indicators.

Case Study	NPV Unlevered	IRR Unlevered	Discounted Payback Period
CS_01	20,720.26	12.46%	Year 4
CS_02	5175.61	8.52%	Year 4
CS_03	−89,093.74	−4.72%	more than 10 years
CS_04	−9467.42	5.50%	more than 10 years
CS_05	−41,690.39	−2.61%	more than 10 years
CS_06	−17,756.17	1.93%	more than 10 years
CS_07	−43,826.51	−4.26%	more than 10 years
CS_08	−55,071.97	−12.54%	more than 10 years
CS_09	12,126.47	12.80%	Year 4
CS_10	10,037.46	11.76%	Year 4
CS_11	−11,162.83	2.87%	more than 10 years
CS_12	−48,814.45	−1.41%	more than 10 years
CS_13	−40,951.20	−2.73%	more than 10 years
CS_14	−72,842.88	−6.15%	more than 10 years
CS_15	−37,690.61	1.92%	more than 10 years
CS_16	−16,902.01	3.72%	more than 10 years
CS_17	−112,217.86	−11.49%	more than 10 years
CS_18	−66,688.32	−5.05%	more than 10 years
CS_19	−58,410.24	−6.65%	more than 10 years
CS_20	−46,114.44	−3.20%	more than 10 years
CS_21	−49,300.80	−10.50%	more than 10 years

3. Results

3.1. Overall Economic Performance

The MCSs show that the economic performance of EPS projects varies considerably depending on building size and financial structure. The scale of the project is defined with reference to the net floor area of the building, which is used as a proxy for the size of the intervention. Based on the distribution of the sample, three representative reference projects were identified: small (66.87 m^2), medium (153.84 m^2) and large (221.34 m^2), corresponding approximately to the minimum, mean and maximum net floor area values.

This classification is used exclusively to differentiate building size, whereas retrofit costs are analysed as a separate variable.

The stochastic analysis highlights a critical financial threshold linked to project magnitude. Small-scale interventions such as CS_08 and CS_21 demonstrate a structural inability to offset high fixed transaction and operational costs, resulting in a mean unlevered NPV of −€45,587 and a small success probability (13.7%). Even when leverage is introduced in the DCF, the probability of achieving a positive NPV remains below 10%, confirming that these projects struggle to generate sufficient cash flows to recover the initial investment.

Medium-sized projects present a more uncertain picture. Expected NPVs are close to zero (around −€8000), and the probability of a positive outcome reaches 47.9% in the unlevered case but drops to 27% when leverage is introduced. This suggests that these

projects operate within a narrow margin, where relatively small changes in key variables can shift the outcome from feasible to unprofitable.

Larger projects, by contrast, show a stronger financial profile. In the unlevered scenario, expected NPV exceeds €20,700, and the probability of achieving a positive outcome rises to 67.1%. Although leverage reduces this probability to around 40%, the overall performance remains significantly more robust compared to smaller-scale interventions.

These results indicate that the financial viability of EPS schemes is not uniform, but strongly dependent on scale. Moving from small to large projects, the model shifts from a structurally unprofitable configuration to a more stable and sustainable situation.

3.2. Risk Distribution and Variability

The dispersion of results is significant across all project categories, reflecting the impact of uncertainty on financial performance (Table 7). Standard deviation values range from approximately €22,600 for small-scale projects to nearly €35,000 for large-scale assets in the unlevered case, confirming that projected cash flows are subject to a considerable degree of variability.

Table 7. Characteristics of the Simulation Distributions.

Cash Flow	Building Size (Net Flood Area)	Mean NPV	Median NPV	Standard Deviation	Min NPV	Max NPV	Prob. NPV > 0 (%)	Prob. NPV < 0 (%)
Unlevered	Small	−45,587.19	−44,699.15	22,633.08	−112,370.74	14,587.93	13.70	86.30
Levered	(66.87 m^2)	−33,125.58	−32,521.44	15,872.82	−79,793.96	8944.43	7.00	93.00
Unlevered	Medium	−8046.18	−7917.09	28,525.97	−92,537.44	71,609.29	47.90	52.10
Levered	(153.84 m^2)	−7846.03	−7741.35	19,705.30	−66,379.44	47,325.56	27.00	73.00
Unlevered	Large	20,721.19	20,641.58	34,929.30	−80,715.13	114,975.26	67.10	32.90
Levered	(221.34 m^2)	11,511.71	11,440.11	23,927.99	−58,434.27	76,354.65	40.00	60.00

Looking more closely at the distributions, clear differences emerge across project scales. For small-scale interventions, the distribution is strongly shifted towards negative values, with an expected NPV of around −€45,600 and only a 13.7% probability of achieving a positive outcome. In addition, downside scenarios can reach values below −€110,000, indicating not only a high likelihood of loss, but also a significant exposure to severe negative outcomes.

In medium-sized projects, the distribution becomes more balanced. Expected NPVs are close to zero (around −€8000), and the probability of positive outcomes increases to approximately 48% in the unlevered case. However, variability remains substantial, with outcomes ranging from roughly −€92,500 to over €70,000. This reflects a situation in which both favourable and unfavourable scenarios are plausible, making financial outcomes highly sensitive to input conditions.

For large-scale assets, the distribution shifts more clearly towards positive values. Expected NPVs exceed €20,000, and the probability of positive outcomes rises above 67%. While downside risk is still present, with minimum values around −€80,000, the upper tail extends beyond €110,000, indicating a stronger potential for positive performance.

Overall, these results suggest that risk in EPS projects is not only a matter of dispersion, but also of how outcomes are distributed around the break-even point (NPV = 0). As project size increases, the balance gradually shifts from predominantly negative outcomes to more stable and favourable configurations, reinforcing the role of scale in shaping both returns and risk exposure.

These distributional patterns are further illustrated in Figure 4.

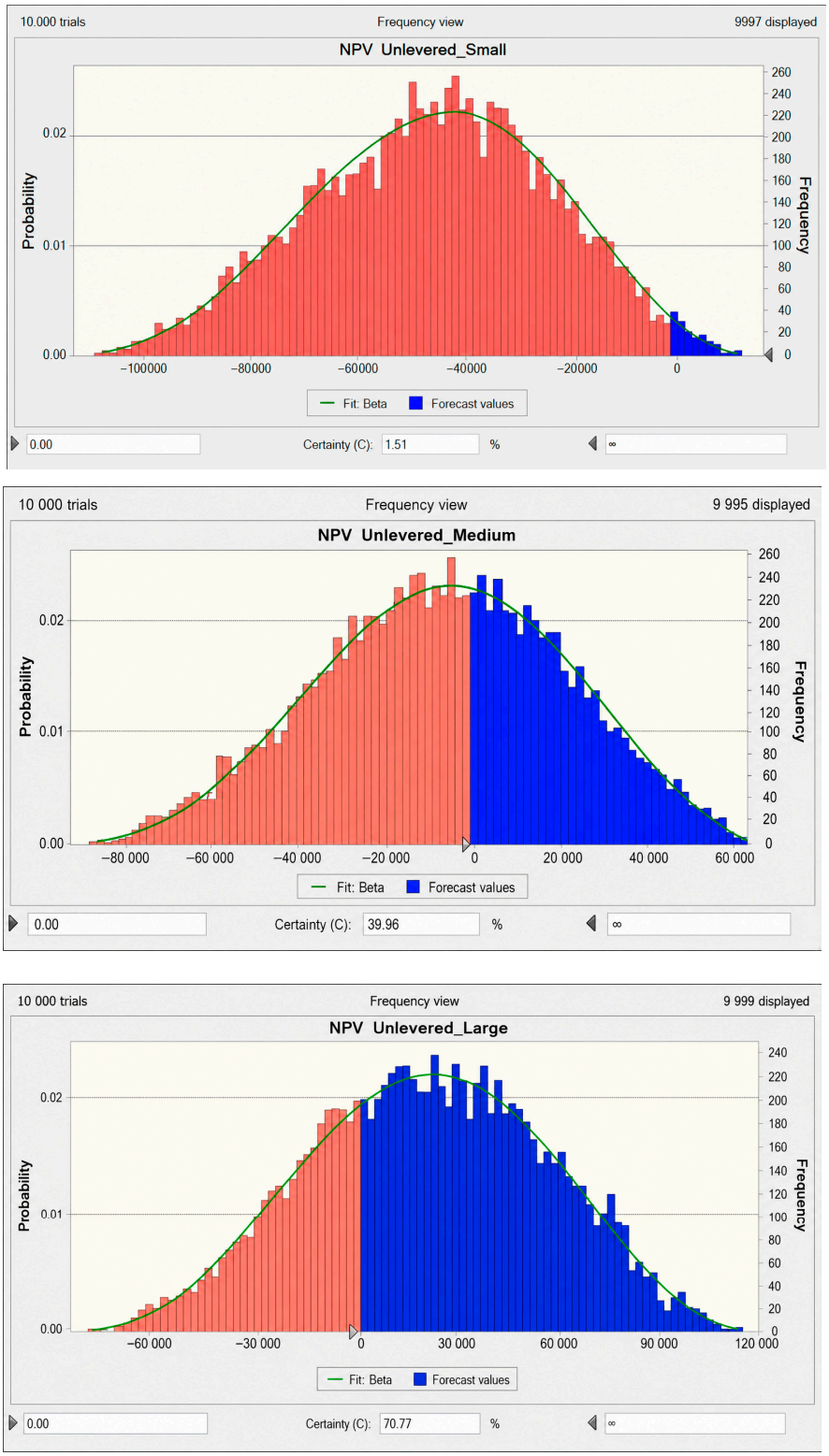


Figure 4. Probability distribution of Net Present Value (NPV) obtained from Monte Carlo simulation for small-, medium-, and large-scale project (unlevered scenario). Small, medium and large refer to net floor area classes defined in Section 3.1. The vertical line indicates the NPV = 0.

3.3. Sensitivity Analysis

Sensitivity analysis was conducted on unlevered configurations (Figure 5) in order to isolate the impact of operational and market variables, excluding the influence of fi-

nancial structuring. A clear and systematic shift emerges in the determinants of financial performance across different project scales.

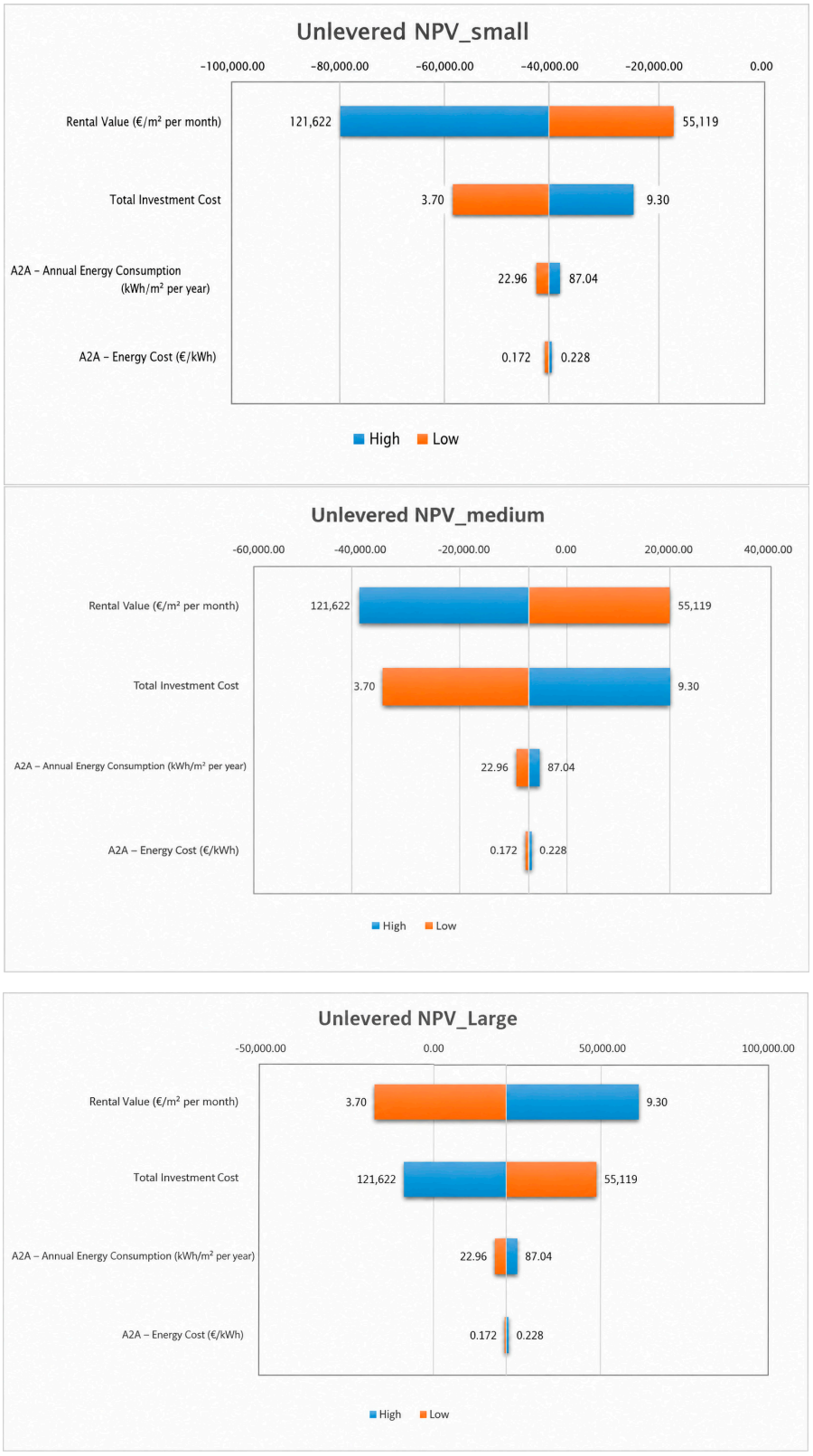


Figure 5. Sensitivity analysis (tornado diagram) showing the contribution of input variables to NPV variability for small-, medium-, and large-scale project. Small, medium and large refer to net floor area classes defined in Section 3.1.

For small-scale assets, NPV variability is overwhelmingly driven by total investment cost. The strong negative relationship between capital expenditure and NPV indicates that project feasibility is primarily constrained by upfront costs. Rental value plays a secondary role, while energy-related variables—including post-retrofit energy consumption and electricity price—exhibit a negligible influence on financial outcomes.

In medium-sized projects, a more balanced sensitivity structure emerges. While investment cost remains the dominant driver, rental value gains substantial importance and becomes a key determinant of NPV variability. This reflects a transitional configuration in which both cost control and market conditions jointly shape financial performance. As a result, medium-scale projects are particularly sensitive to uncertainty, with outcomes depending on the interaction between capital expenditure and achievable rental income.

For large-scale assets, the sensitivity structure changes significantly. Rental value becomes the primary driver of NPV, surpassing investment cost in terms of influence. This indicates that financial performance is increasingly determined by real estate market conditions, as larger projects benefit from economies of scale that mitigate the relative impact of upfront costs. In this context, revenue generation plays a central role in ensuring project viability.

Across all project sizes, energy-related variables consistently exhibit a limited contribution to NPV variability. Although energy efficiency improvements remain central from a technical and environmental perspective, their direct impact on financial performance appears secondary compared to economic and market factors.

Overall, the analysis reveals a scale-dependent transformation in financial risk drivers. Small projects are primarily cost-driven, medium projects reflect a balance between costs and revenues, and large projects are predominantly market-driven. This finding highlights the importance of project scale in shaping both financial performance and risk exposure within EPS schemes.

3.4. Effect of Financial Structure

To assess the impact of capital structure on project performance, leveraged scenarios were compared with their unlevered counterparts.

The introduction of leverage tends to reduce financial resilience in projects characterised by relatively weak or volatile operating cash flows. Across all building sizes, leveraged configurations exhibit lower expected NPVs and a reduced probability of achieving positive returns. This effect reflects the additional burden of debt servicing, which amplifies downside risk under conditions of uncertain cash flows.

Despite these differences in performance, the sensitivity structure remains remarkably stable across financial configurations. The same key variables—namely investment cost and rental value—consistently dominate NPV variability in both leveraged and unlevered scenarios. In particular, small-scale projects remain primarily cost-driven, medium-scale projects exhibit a balanced sensitivity to both costs and revenues, and large-scale assets continue to be predominantly influenced by rental market conditions.

Energy-related variables retain a marginal role across all configurations, confirming that financial performance is largely driven by economic and market factors rather than by energy price dynamics.

These findings suggest that leverage affects the magnitude and distribution of financial outcomes, but does not alter the underlying economic drivers of EPS projects. As such, project viability is primarily determined by scale, cost efficiency, and local real estate market conditions, while financial structuring plays a secondary, amplifying role.

4. Discussion

The results of this study highlight the central role of project scale in shaping the financial performance of Energy Plus Service (EPS) schemes under uncertainty.

Financial outcomes vary markedly across building sizes, reflecting the impact of fixed and transaction costs on smaller interventions. Limited revenue streams make it difficult for small projects to recover initial investments, whereas larger projects are better able to absorb costs and generate stable returns. This suggests that, in fragmented residential markets, aggregation mechanisms and public incentives (e.g., Ecobonus schemes) may be necessary to support the viability of smaller-scale EPS projects.

The analysis shows that the nature of financial risk changes across scales. In smaller projects, variability in NPV is driven mainly by capital expenditure, while in larger projects it is more closely linked to rental values. This indicates that EPS performance is not determined solely by technical efficiency, but also by the ability to capture value within the real estate market.

These results are broadly consistent with previous studies on Energy Performance Contracting and Energy-as-a-Service, which have highlighted the importance of project size and transaction costs in shaping financial feasibility, especially in fragmented residential markets. These findings support Hannon et al.'s and Bolton and Foxon's arguments on the need to overcome scale barriers through aggregation mechanisms and integrated service propositions [50]. At the same time, the increasing importance of rental value in larger projects reinforces the literature on "green premiums" in real estate markets, where improved energy performance and service quality can translate into higher rents and better risk-adjusted returns [51,52].

A simple interpolation between the medium- and large-scale unlevered cases suggests that projects approaching 160 m^2 are more likely to achieve a 50% probability of a positive NPV. This should be read as an indicative threshold rather than a precise cut-off. Under leverage, this condition is not met within the observed range, indicating that larger project sizes would be required.

These results highlight how a physical characteristic of the asset—namely net floor area—may act as a critical discriminator of project viability. Although larger projects entail higher absolute retrofit and management costs, these are partly offset by fixed and quasi-fixed components that are diluted over a greater floor area, while rental and service revenues scale more than proportionally in risk-adjusted terms, leading to higher and more stable NPVs for medium- and large-scale projects. Within the analysed market context, projects approaching 160 m^2 appear more likely to achieve a 50% probability of a positive NPV in unlevered configurations, suggesting that the EPS model may function without relying exclusively on the direct involvement of financial institutions, and that scale itself becomes an important precondition for generating bankable EPS projects. Below this indicative threshold, individual dwellings are unlikely to sustain EPS schemes without aggregation mechanisms, enhanced public support, or more favourable financing conditions, whereas portfolios clustering projects at or above this scale are more likely to pass an NPV-based investment screen.

The findings also relate to the well-known "split incentive" problem in rental markets, particularly for small landlords who struggle to recover fixed and transaction costs [53–57]. In this context, aggregation and portfolio-based EPS schemes can help align incentives by spreading costs and benefits across multiple dwellings, rather than relying on individual units to reach viability independently [50,51,53,54,56,58].

These results also shed light on a broader set of questions that are highly relevant for practice, notably how a mixed-portfolio EPS product could be structured, which risk-

hedging mechanisms might be adopted, and why individual homeowners would have an incentive to join such schemes rather than simply doing nothing.

One possible approach would be to aggregate geographically proximate dwellings requiring similar retrofit interventions into portfolio-based EPS schemes capable of reaching the identified viability threshold. Aggregating highly heterogeneous projects would be difficult to market, as households would be reluctant to pay for a "blended" service that includes works and cost components not relevant to their own dwelling.

In practical terms, a portfolio-based EPS scheme could combine smaller, individually marginal projects with larger and financially stronger interventions within the same contractual structure. Such aggregation would allow for fixed and transaction costs to be distributed across a broader asset base while improving the overall portfolio risk profile through cash-flow diversification. For smaller homeowners and landlords, participation in a bundled scheme may reduce individual exposure to technical and financial risks, facilitate access to financing mechanisms that would otherwise be unavailable, and lower transaction and coordination costs through shared project management. This mechanism may be particularly relevant for smaller owners, who often face tighter financial constraints and more limited technical or administrative capacity to manage complex retrofit interventions independently. Such portfolio-based schemes could also be supported by targeted de-risking instruments, such as soft loans or public guarantee mechanisms, which may further improve access to financing and reduce the barriers faced by smaller homeowners.

Financial risk would initially be absorbed by the service provider, in line with the EPS economic model, and subsequently shared among participating households through the service fee. From a risk perspective, exposure is not concentrated on a single homeowner but diversified across the entire portfolio. Defaults or under-performance in one unit would be partially offset by more robust cash flows in others, provided that adequate contractual safeguards and enforcement mechanisms are in place to manage non-payment and free-riding.

For homeowners, the main benefit of joining such a portfolio-based EPS scheme is not only the direct improvement in energy performance and comfort, but also the preservation of relative asset value. Real estate valuation literature has long emphasised that property value depends on a combination of intrinsic and extrinsic attributes, and that these are strongly interconnected [51,52]. A dwelling in a prime location that remains inefficient, outdated and surrounded by recently renovated, high-performance buildings is likely to suffer a relative discount, as documented by empirical studies on the price premium associated with higher energy classes [51,52]. Previous studies on social and residential housing retrofits have also shown that households excluded from renovation processes may experience relative asset devaluation compared to upgraded neighbouring properties. Portfolio-based EPS schemes can help address both problems: they provide a structured vehicle for upgrading multiple units in a coordinated way, and they reduce the risk that financially constrained households are "left behind" in markets where energy-efficient stock progressively becomes the norm [59,60].

In addition, behavioural and peer effects may further support participation in retrofit initiatives when similar interventions become visible within the local social context [52,59,60], creating a "chain reaction".

A second important aspect concerns the drivers of financial performance. The sensitivity analysis indicates that investment costs and rental income are the main determinants of economic outcomes, while energy-related variables play a comparatively limited direct role. Although energy performance improvements remain essential from an environmental standpoint, their financial impact appears to be mediated by market conditions. In this

sense, the success of EPS models depends not only on technical design, but also on the stability and level of revenue streams that can be achieved.

The contrast between the EPC and EPS configurations also helps explain why households may resist models that resemble Figure 2. When tenants or homeowners are required to commit to long-term service fees that internalise both investment and operating risks, perceived downside exposures become a major barrier, especially in small-scale projects with thin or volatile cash flows. By comparison, EPC-type arrangements partially shift technical and financial risks toward the ESCo and financial intermediaries, reducing the direct burden placed on households.

The role of financial structure further reinforces this interpretation. The introduction of leverage does not improve project viability and, in several cases, increases downside risk. This reflects the difficulty of sustaining debt obligations under uncertain and relatively constrained cash flows. At the same time, the structure of the model remains unchanged: leverage affects the magnitude of results, but not the underlying drivers of performance.

From a policy perspective, these findings both support and challenge current retrofit frameworks. While incentives such as Ecobonus and Superbonus contribute to de-risking investments and improving the financial attractiveness of EPS schemes, the pronounced scale effects identified in this study suggest that existing measures may disproportionately favour larger and more structured projects. Without dedicated mechanisms for project aggregation and portfolio-based financing, the objective of mass-market deep renovation may evolve at "two speeds", with smaller homeowners facing structurally weaker economic conditions.

The role of funding structures is also critical in interpreting these results. In the analysed context, EPS projects are typically financed through a mix of public support, bank lending and private equity from homeowners and landlords. Public support mechanisms effectively act as de-risking instruments, reducing the upfront equity requirement and partially compensating for the weakness of small-scale projects. However, the study's simulations show that, once these supports are reduced or withdrawn, debt-funded configurations can exacerbate downside risk, particularly when cash flows remain close to break-even. This raises important implications for both lenders, who face higher credit risk in small, highly leveraged projects, and homeowners, whose capacity to provide equity is often constrained. In this setting, more balanced funding mixes—combining moderate leverage with targeted public guarantees or soft loans—may be necessary to sustain EPS schemes, especially for smaller assets that cannot rely on scale alone.

From the perspective of financial institutions, the probabilistic framework adopted in this study can be interpreted as a simplified representation of their investment decision process. Rather than relying solely on point estimates, the analysis evaluates the full distribution of NPVs, including expected values, tail outcomes and the probability of loss, which are critical for determining whether to finance or reject an EPS project. In this sense, the results provide insight into how risk-sensitive intermediaries may selectively support projects combining sufficient scale with an acceptable balance between upside potential and downside exposure.

Finally, some limitations should be acknowledged. The analysis is based on a relatively small sample within a specific regional context, which may limit the generalisability of the results. In addition, the modelling relies on assumptions regarding input distributions and market parameters that may influence the outcomes. Future research could extend the analysis to larger datasets, explore alternative contractual arrangements, and further investigate the role of institutional and behavioural factors in shaping the performance of energy service models.

5. Conclusions

This study set out to examine the economic viability of Energy Plus Service (EPS) models applied to residential retrofits under uncertainty, combining deterministic financial modelling with a probabilistic simulation approach.

EPS schemes cannot be assessed independently of project scale, understood here in objective terms as the net floor area of the building and the associated investment volume. In the analysed portfolio, small interventions correspond to single-family houses of around 70 m^2, with total investments typically below EUR 90,000; medium-sized projects cluster around 150–160 m^2 and mid-range investment volumes; larger projects exceed 200 m^2 and are associated with investments often above EUR 150,000. Within this range, a financial viability threshold emerges around 160 m^2, beyond which the probability of achieving a positive NPV exceeds approximately 50% in unlevered configurations. This value can be interpreted as a rule-of-thumb threshold for project design and screening. Individual dwellings below this size are unlikely to sustain EPS schemes without aggregation, enhanced public support or more favourable financing conditions, whereas projects at or above this scale have a structurally higher chance of meeting risk–return requirements for risk-averse investors and financial intermediaries. Our findings are consistent with Hannon's argument that the service model becomes viable only when scale barriers are overcome through aggregation [50].

The analysis also highlights that financial performance is driven primarily by economic and market variables. Cost structure and rental values emerge as the key determinants of NPV, while energy-related factors play a more limited direct role. In other words, improving energy performance is necessary, but not sufficient, to ensure economic viability. This does not reduce the importance of energy efficiency from a policy perspective, but highlights that its financial impact is mediated by broader economic conditions.

The central role of rental values also raises the question of how robust these findings are to future changes in rental market conditions. The scenarios analysed in this study are anchored to current OMI benchmarks for "excellent condition" units in the study area; a downward shift in rental levels—for instance due to macroeconomic shocks or regulatory constraints on rent increases—would reduce the profitability of EPS schemes, particularly for medium and large projects whose performance is more strongly driven by market revenues. Under such conditions, the viability threshold identified around 160 m^2 would likely shift upwards, and a larger share of projects would require either additional public support or more favourable financing terms to remain viable. Conversely, in contexts where rental markets remain tight or continue to reward high-performance buildings, EPS schemes may become attractive even for projects closer to the lower end of the current scale spectrum. Therefore, the recommendations put forward in this paper—particularly those concerning aggregation and de-risking instruments—should be interpreted as conditional on rental markets remaining within the broad range observed in the empirical data, and may need recalibration if rental dynamics change substantially.

The role of financial structure further reinforces this picture. The introduction of leverage tends to increase downside exposure, particularly in projects operating close to break-even conditions. This suggests that financial engineering alone cannot compensate for structural weaknesses related to scale or market conditions.

These findings point to a broader issue. While policy frameworks strongly promote energy efficiency and deep renovation, the economic conditions required to support private investment are not always in place. Bridging this gap may require a stronger focus on financial mechanisms, such as targeted incentives, risk-sharing tools, or aggregation strategies that allow smaller projects to benefit from scale.

The identification of a financial viability threshold at approximately 160 m^2 necessitates a strategic redirection of public policy. To prevent the natural exclusion of smaller residential units from the EPS market, intervention should shift from distortive blanket subsidies toward fostering project aggregation through One-Stop Shops (OSSs), thereby diluting transaction costs across larger portfolios. Furthermore, addressing the fragility of small-scale interventions requires targeted de-risking instruments—such as first-loss guarantees or soft loans.

These findings reinforce the idea that EPS is not only a technical issue, but also a matter of positioning within the real estate market.

This study is not without limitations. The analysis is based on a relatively small sample within a specific regional context, and the modelling relies on assumptions that may influence the results. Future research could extend the analysis to larger datasets, explore and compare alternative contractual models, and further investigate how behavioural and institutional factors affect the performance of energy service schemes.

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Abbreviations

The following abbreviations are used in this manuscript:

DCF	Discounted Cash Flow
NPV	Net Present Value
EPS	Energy Plus Service
MC	Monte Carlo
WACC	Weighted Cost of Capital
t	Time period
T	Project horizon
g	Growth rate (inflation rate)
r	Discount rate
CF_t	Net Cash Flow in Period t:
R_0	Net Rent Revenue
E_0	Net Revenues from Energy Services
I_0	Investment costs

Appendix A

Table A1. Energy class conversion for Oracle Crystal Ball simulations.

Case Study	CE_Prior ($kWhm^2$)	CE_Post ($kWhm^2$)	CE_Prior Crystal Ball	CE_Post Crystal Ball
CS_01	A1	A4	110	45
CS_02	D	A2	195	90
CS_03	F	A4	350	45

Table A1. *Cont.*

Case Study	CE_Prior (kWhm^2)	CE_Post (kWhm^2)	CE_Prior Crystal Ball	CE_Post Crystal Ball
CS_04	E	C	260	165
CS_05	G	E	450	260
CS_06	D	A3	195	65
CS_07	F	A3	350	65
CS_08	G	A4	450	45
CS_09	C	A4	165	45
CS_10	C	A4	165	45
CS_11	E	C	260	165
CS_12	D	A1	195	110
CS_13	C	A3	165	65
CS_14	F	A4	350	45
CS_15	G	A4	450	45
CS_16	G	A1	450	110
CS_17	G	A4	450	45
CS_18	D	A4	195	45
CS_19	E	A1	260	110
CS_20	F	A1	350	110
CS_21	D	A1	195	110

References

1. Maduta, C.; Melica, G.; D'Agostino, D.; Bertoldi, P. Towards a decarbonised building stock by 2050: The meaning and the role of zero emission buildings (ZEBs) in Europe. *Energy Strategy Rev.* **2022**, *44*, 101009. [CrossRef]
2. Economidou, M.; Todeschi, V.; Bertoldi, P.; D'Agostino, D.; Zangheri, P.; Castellazzi, L. Review of 50 years of EU energy efficiency policies for buildings. *Energy Build.* **2020**, *225*, 110322. [CrossRef]
3. Bertoldi, P. Editorial: Ten-year anniversary issue. *Energy Effic.* **2018**, *11*, 1913–1915. [CrossRef]
4. Moles-Grueso, S.; Bertoldi, P.; Boza-Kiss, B. *Energy Performance Contracting in the EU—2020–2021*; Publications Office of the European Union: Luxembourg, 2023. [CrossRef]
5. López-González, L.M.; López-Ochoa, L.M.; Las-Heras-Casas, J.; García-Lozano, C. Energy performance certificates as tools for energy planning in the residential sector. The case of La Rioja (Spain). *J. Clean. Prod.* **2016**, *137*, 1280–1292. [CrossRef]
6. Ibañez Iralde, N.S.; Pascual, J.; Salom, J. Energy retrofit of residential building clusters. A literature review of crossover recommended measures, policies instruments and allocated funds in Spain. *Energy Build.* **2021**, *252*, 111409. [CrossRef]
7. Salvalai, G.; Sesana, M.M.; Iannaccone, G. Deep renovation of multi-storey multi-owner existing residential buildings: A pilot case study in Italy. *Energy Build.* **2017**, *148*, 23–36. [CrossRef]
8. Elgendy, R.; Mlecnik, E.; Visscher, H.; Qian, Q. Integrated home renovation services as a means to boost energy renovations for homeowner associations: A comparative analysis of service providers' business models. *Energy Build.* **2024**, *320*, 114589. [CrossRef]
9. Tukker, A. Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. *Bus. Strategy Environ.* **2004**, *13*, 246–260. [CrossRef]
10. Bisello, A.; Antoniucci, V.; Marella, G. Measuring the price premium of energy efficiency: A two-step analysis in the Italian housing market. *Energy Build.* **2020**, *208*, 109670. [CrossRef]
11. Evangelista, R.; Ramalho, E.A.; Andrade e Silva, J. On the use of hedonic regression models to measure the effect of energy efficiency on residential property transaction prices: Evidence for Portugal and selected data issues. *Energy Econ.* **2020**, *86*, 104699. [CrossRef]
12. Biasin, M.; Delle Foglie, A.; Giacomini, E. Addressing climate challenges through ESG-real estate investment strategies: An asset allocation perspective. *Financ. Res. Lett.* **2024**, *63*, 105381. [CrossRef]
13. Marmolejo-Duarte, C.; Chen, A. The effect of energy performance ratings over residential prices or how an insufficient control of architectural-quality may render spurious conclusions. *Cities* **2022**, *126*, 103674. [CrossRef]
14. Lee, W.L.; Yik, F.W.H. Regulatory and voluntary approaches for enhancing building energy efficiency. *Prog. Energy Combust. Sci.* **2004**, *30*, 477–499. [CrossRef]
15. Wang, Z.; Xu, G.; Lin, R.; Wang, H.; Ren, J. Energy performance contracting, risk factors, and policy implications: Identification and analysis of risks based on the best-worst network method. *Energy* **2019**, *170*, 1–13. [CrossRef]

16. Zhang, W.; Yuan, H. Promoting energy performance contracting for achieving urban sustainability: What is the research trend? *Energies* **2019**, *12*, 1443. [CrossRef]
17. Martiniello, L.; Morea, D.; Paolone, F.; Tiscini, R. Energy performance contracting and public-private partnership: How to share risks and balance benefits. *Energies* **2020**, *13*, 3625. [CrossRef]
18. Langlois, P.; Tanguay, D. Measurement & Verification: At the Core of Energy Performance Contracting. M&V Focus 2021, Issue 9, November. Available online: https://evo-world.org/en/m-v-community/mv-focus/890-november-2021-m-v-focus-issue-9/1223-measurement-verification-at-the-core-of-energy-performance-contracting (accessed on 15 April 2026).
19. Carbonara, N.; Pellegrino, R. Public-private partnerships for energy efficiency projects: A win-win model to choose the energy performance contracting structure. *J. Clean. Prod.* **2018**, *170*, 1064–1075. [CrossRef]
20. Brown, D. Business models for residential retrofit in the UK: A critical assessment of five key archetypes. *Energy Effic.* **2018**, *11*, 1497–1517. [CrossRef]
21. Brown, D.; Sorrell, S.; Kivimaa, P. Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit. *Energy Policy* **2019**, *128*, 418–430. [CrossRef]
22. Bertoldi, P.; Rezessy, S.; Vine, E. Energy service companies in European countries: Current status and a strategy to foster their development. *Energy Policy* **2006**, *34*, 1818–1832. [CrossRef]
23. Sorrell, S. The economics of energy service contracts. *Energy Policy* **2007**, *35*, 507–521. [CrossRef]
24. Gazzetta Ufficiale della Repubblica Italiana. Decreto Legislativo 30 Maggio 2008, n. 115; 2008. Pubblicato Nella GU Serie Generale n.154 del 03-07-2008. Available online: https://www.gazzettaufficiale.it/eli/id/2008/07/03/008G0137/sg (accessed on 13 April 2026).
25. Zabot, S.; Santo, D.D. *Guida ai Contratti di Prestazione Energetica Negli Edifici Pubblici*; ENEA: Rome, Italy, 2013.
26. Ministero dello Sviluppo Economico. Decreto 26 Giugno 2015, Recante "Applicazione Delle Metodologie Di Calcolo Delle Prestazioni Energetiche E Definizione Delle Prescrizioni e dei Requisiti Minimi Degli Edifici"; 2015. Pubblicato Nella GU Serie Generale n.164 del 15 July 2015. Available online: https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2015-07-15&atto.codiceRedazionale=15A05199 (accessed on 12 April 2026).
27. Carlo, F.; De Rossi, B. *Principi di Economia ed Estimo*; Rizzoli: New York, NY, USA, 1974.
28. Del Giudice, V. *Estimo e Valutazione Economica dei Progetti. Profili Metodologici e Applicazioni al Settore Immobiliare*; Paolo Loffredo Editore: Naples, Italy, 2015; p. 376.
29. Simonotti, M. Una Misura Quantitativa Della Verosimiglianza Estimativa. Aestimum 1989. DOI: 10.13128/Aestimum-8233. Available online: https://www.scienceopen.com/document?vid=4eda7a3e-e01c-4e6b-a78a-41bc3815ab44 (accessed on 3 April 2026).
30. Barbu, A.; Zhu, S.-C. *Monte Carlo Methods*; Springer: Berlin/Heidelberg, Germany, 2018. [CrossRef]
31. Casella, G.; Fienberg, S.; Olkin, I. *Monte Carlo Statistical Methods*; Springer Science + Business Media: New York, NY, USA, 2004. [CrossRef]
32. Hoesli, M.; Jani, E.; Bender, A. Monte Carlo simulations for real estate valuation. *J. Prop. Invest. Financ.* **2006**, *24*, 102–122. [CrossRef]
33. Metropolis, N.; Ulam, S. The Monte Carlo Method. 1949. Available online: https://about.jstor.org/terms (accessed on 2 April 2026).
34. Rubinstein, R.Y.; Kroese, D.P. *Simulation and the Monte Carlo Method*; Wiley: Hoboken, NJ, USA, 2017; p. 414.
35. Barañano, A.; De La Peña, J.I.; Moreno, R. Valuation of real-estate losses via Monte Carlo simulation. *Econ. Res.-Ekon. Istraz.* **2020**, *33*, 1867–1888. [CrossRef]
36. Jayaraman, S. *A Review of Monte Carlo Methods in Real Estate*; Term Project Report, CIS 5930/ISC 5932: Monte Carlo Methods; Florida State University: Tallahassee, FL, USA, 2 May 2013. Available online: https://ww2.cs.fsu.edu/ jayarama/RealEstateMCMReport.pdf (accessed on 13 April 2026).
37. Evans, A.H. Monte Carlo Analysis: A Practical Application to Development Appraisal. *J. Prop. Financ.* **1996**, *3*, 271–281. [CrossRef]
38. French, N.; Gabrielli, L. The uncertainty of valuation. *J. Prop. Invest. Financ.* **2004**, *22*, 484–500. [CrossRef]
39. Gimpelevich, D. Simulation-based excess return model for real estate development. *J. Prop. Invest. Financ.* **2011**, *29*, 115–144. [CrossRef]
40. Arnold, U.; Yildiz, Ö. Economic risk analysis of decentralized renewable energy infrastructures—A Monte Carlo Simulation approach. *Renew. Energy* **2015**, *77*, 227–239. [CrossRef]
41. Hacura, A.; Jadamus-Hacura, M.; Kocot, A. Risk analysis in investment appraisal based on the Monte Carlo simulation technique. *Eur. Phys. J. B-Condens. Matter Complex Syst.* **2001**, *20*, 551–553. [CrossRef]
42. Platon, V.; Constantinescu, A. Monte Carlo Method in Risk Analysis for Investment Projects. *Procedia Econ. Financ.* **2014**, *15*, 393–400. [CrossRef]
43. Shaffie, S.S.; Jaaman, S.H. Monte Carlo on Net Present Value for Capital Investment in Malaysia. *Procedia-Soc. Behav. Sci.* **2016**, *219*, 688–693. [CrossRef]

44. Brealey, R.A.; Myers, S.C.; Allen, F. *Principles of Corporate Finance: S&P Market Insight*, 10th ed.; in The McGraw-Hill/Irwin series in finance, insurance, and real estate; McGraw-Hill Irwin: New York, NY, USA, 2011.
45. Damodaran, A. Betas by Sector (Global) or Betas by Sector (US). Available online: https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datafile/BetasGlobal.html (accessed on 15 April 2026).
46. Yescombe, E.R. *Principles of Project Finance*; YCL Consulting Ltd.: London, UK, 2018. [CrossRef]
47. Miyamoto, K.; Chiofalo, E. *Official Development Finance for Infrastructure: Support by Multilateral and Bilateral Development Partners*; OECD Development Co-operation Working Papers, No. 25; OECD Publishing: Paris, France, 2015. Available online: https://www.oecd.org/dac/official-development-finance-for-infrastructure.htm (accessed on 13 April 2026).
48. DEI. *Prezzi Informativi dell'Edilizia. Nuove Costruzioni. 1° Semestre 2024. Materiali ed Opere Compiute*; Rilevazione Prezzi; DEI: Rome, Italy, 2024.
49. Castellazzi, L.; Bertoldi, P.; Economidou, M. *Overcoming the Split Incentive Barrier in the Building Sector—Unlocking the Energy Efficiency Potential in the Rental & Multifamily Sectors*; Publications Office of the European Union: Luxembourg, 2017. [CrossRef]
50. Azimi, S.; Hon, C.K.H.; Tyvimaa, T.; Skitmore, M. Barriers to Energy Efficiency: Low-Income Households in Australia. *Buildings* **2023**, *13*, 954. [CrossRef]
51. Bird, S.; Hernández, D. Policy options for the split incentive: Increasing energy efficiency for low-income renters. *Energy Policy* **2012**, *48*, 506–514. [CrossRef]
52. Singhal, P.; Sommer, S.; Kaestner, K.; Pahle, M. Split-incentives in energy efficiency investments? Evidence from rental housing. *Resour. Energy Econ.* **2025**, *82*, 101488. [CrossRef]
53. Hannon, M.J.; Foxon, T.J.; Gale, W.F. The co-evolutionary relationship between Energy Service Companies and the UK energy system: Implications for a low-carbon transition. *Energy Policy* **2013**, *61*, 1031–1045. [CrossRef]
54. Charles, H.; Bouzarovski, S.; Bellamy, R.; Gormally-Sutton, A. 'Although it's my home, it's not my house'—Exploring impacts of retrofits with social housing residents. *Energy Res. Soc. Sci.* **2025**, *119*, 103869. [CrossRef]
55. Alam, Z.; Hossain, M.; Wang, L. The economic and cultural motives of green price premium. *Br. Account. Rev.* **2025**, *57*, 101698. [CrossRef]
56. Loberto, M.; Mistretta, A.; Spuri, M. The Capitalization of Energy Labels into House Prices. Evidence from Italy. *SSRN Electron. J.* **2024**, 38 pages. [CrossRef]
57. Touchie, M.F. Resident-centric retrofits for social housing: A multi-solving approach. *Indoor Environ.* **2025**, *2*, 100131. [CrossRef]
58. He, S.; Qian, Q.K. Planning home energy retrofit in a social environment: The role of perceived descriptive and injunctive social norms. *Sustain. Cities Soc.* **2023**, *99*, 104954. [CrossRef]
59. Bakaloglou, S.; Charlier, D. The role of individual preferences in explaining the energy performance gap. *Energy Econ.* **2021**, *104*, 105611. [CrossRef]
60. Charlier, D. Explaining the energy performance gap in buildings with a latent profile analysis. *Energy Policy* **2021**, *156*, 112480. [CrossRef]

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