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Financing energy efficiency: Barriers, instruments, and pathways to scale

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PEER-REVIEWED PAPER

PAOLO BERTOLDI

ABSTRACT

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Energy efficiency is widely recognised as the most cost-effective solution available to reduce energy consumption, cut greenhouse gas emissions, and enhance energy security. Yet a persistent and large investment gap separates what is economically justified from what is actually financed. This paper analyses the barriers that explain this gap, from small and fragmented projects to the risk aversion of commercial lenders and structural split incentives that misalign costs and benefits, and examines the principal instruments developed to address them. The analysis proceeds from traditional public financing tools, subsidies, grants, fiscal incentives, and zero-or low-interest loans, through progressively more market-based mechanisms: Energy Performance Contracts delivered by energy service companies, Pay-As-You-Save and on-bill financing, Property-Assessed Clean Energy financing, green mortgages, white certificate obligation schemes, feed-in tariffs for energy savings, and carbon taxes and emissions trading systems revenues as sources of public co-financing. The paper further examines cross-cutting enablers, including de-risking instruments, project aggregation, one-stop shops, and secondary markets. For each instrument, it considers the underlying logic, the market failure addressed, the empirical evidence on effectiveness, and the conditions for success or failure. The paper concludes that no single instrument is sufficient: a layered policy architecture combining direct public support, risk transfer mechanisms, and market-based incentives calibrated to national context and sector offers the most robust pathway to closing the energy efficiency financing gap.

CORRESPONDING AUTHOR:
Paolo Bertoldi

Independent expert, Luxembourg

paolo.bertoldi1@gmail.com

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energy efficiency gap; financing barriers; ESCO; energy performance contracts; on-bill financing; PACE; green mortgages; white certificates; carbon tax; ETS revenues; de-risking; project aggregation; secondary markets; blended finance

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1. INTRODUCTION

Energy efficiency projects typically entail large up-front investments to implement technologies and solutions, for example renovation of existing buildings or the installation of high-efficiency equipment. In most cases energy efficiency investments are profitable, in the sense that the financial savings arising from reduced energy consumption exceed the initial capital outlay (Bremer et al., 2024), often with additional non-energy benefits such as improved comfort, health gains, and increased property value (Rasmussen, 2017). Yet despite these compelling economics, the pace of energy efficiency investment globally remains far below what is required under any scenario consistent with the Paris Agreement temperature goals.

The International Energy Agency estimates that annual global investment in energy efficiency must reach approximately USD 1.8 trillion per year by 2030, more than three times the current level, to stay on track for net zero (IEA, 2023). As later sections show, this gap is rooted not in technology but in barriers that prevent economically rational investments from being conceived, structured, funded, and executed through conventional financial channels.

This paper analyses both the barriers and the instruments designed to address them. Section 2 examines the nature and persistence of the energy efficiency investment gap; Section 3 analyses the financing barriers in depth; Sections 4 through 11 examine the instruments developed to overcome these barriers, beginning with traditional public financing tools and proceeding through progressively more market-based mechanisms, as well as cross-cutting enablers such as de-risking, project aggregation, and secondary market development; Section 12 provides a comparative assessment and policy framework; and Section 13 concludes.

2. THE ENERGY EFFICIENCY INVESTMENT GAP

The concept of the energy efficiency gap, the divergence between the level of energy efficiency investment that would be economically rational given observed energy prices, technology costs, and discount rates, and the level actually observed in practice, was formally introduced by Hirst and Brown (1990) and has since generated extensive theoretical and empirical inquiry. The gap can be measured at multiple levels: between the technically feasible and the economic optimum; between the economic optimum and actual investment; and between current investment trajectories and the level required to meet specific policy targets, each yielding a different but consistently large magnitude.

At the global level, the IEA estimates that energy intensity (primary energy consumption per unit of GDP) improved at an average annual rate of just 1.5% over the decade to 2022, compared to the 4% annual improvement required under the Net Zero Scenario (IEA, 2023). In the EU, the European Commission's own assessments consistently find that member states are on course to achieve only 60–70% of their indicative energy efficiency targets under the Energy Efficiency Directive (European Commission, 2025). The Climate Policy Initiative estimates that annual energy efficiency investment globally reached approximately USD 600 billion in 2022, implying an annual shortfall of over USD 1.2 trillion against the net zero requirement (Climate Policy Initiative, 2023). This shortfall is not evenly distributed: advanced economies account for the majority of current investment, while emerging markets and developing economies, home to the fastest-growing stock of energy-consuming buildings and industrial facilities, attract a disproportionately small share of financing.

A number of barriers prevent profitable investments in energy efficiency, including long payback periods, uncertain returns due to fluctuations in energy prices, and split incentives between owners and tenants (Cattaneo, 2019), as well as limited access to external funding, lack of specialised expertise, complex project structures, and high perceived risks (Koutsandreas et al., 2022). Many organisations face internal budget limitations, or prioritise core business investments over energy efficiency due to conservative financial strategies (Schleich and Gruber, 2008).

Many energy efficiency projects are small-scale, leading to high transaction and due diligence costs relative to project size, and it is often complex to identify and aggregate projects in sectors like residential buildings (Lundmark, 2024; Nicolas and Molina-Costa, 2021). Financial institutions often view energy efficiency as risky due to limited data on performance and lack of technical expertise to assess projects (Dong and Huo, 2017), compounded by low awareness of benefits among building owners and a lack of standardised frameworks for quantifying and communicating the financial value of energy savings to lenders. These barriers, namely upfront capital requirements, split incentives, small project size and fragmentation, lender risk aversion, and information asymmetry, are examined in depth in Section 3.

3. BARRIERS TO FINANCING ENERGY EFFICIENCY

3.1 THE UPFRONT CAPITAL HURDLE AND SPLIT INCENTIVES

The most immediately intuitive barrier is the requirement for upfront capital expenditure to generate future savings. This creates a temporal mismatch between costs and benefits that is particularly problematic for actors who face liquidity constraints, operate under short-term planning horizons, or have high effective discount rates. Households, especially low- and middle-income households, frequently cannot or will not deploy savings or access credit for home energy improvements, even when the long-term financial case is strong. Small and medium-sized enterprises (SMEs) typically operate with thin margins and tight working capital, making it difficult to justify capital allocation to energy efficiency when core business investment competes for the same scarce funds. Even where financing is available, end-users may remain reluctant to take on debt for investments whose economic returns are perceived as uncertain or long-term (Niknafs et al., 2024). Loans often fail to fully address the structural mismatch between high upfront costs and delayed or uncertain benefits.

Compounding the capital barrier is the problem of split incentives. In rental markets, a landlord who invests in building insulation or an efficient heating system reduces the energy costs of tenants who pay the utility bills, not the owner's own costs. Without a mechanism to capture the value of the efficiency investment in higher rents or property prices, a link that is weak in many housing markets, property owners face a rational disincentive to invest (Gillingham and Palmer, 2014). The problem is symmetrical: tenants who bear energy costs have little incentive to invest in a property they do not own. Estimates suggest that split incentive problems affect between 30% and 40% of the European residential building stock (Castellazzi et al., 2017).

3.2 SMALL PROJECT SIZE, MARKET FRAGMENTATION, AND TRANSACTION COSTS

A structural feature of the energy efficiency market that severely complicates financing is the small size of most individual projects relative to the transaction costs of arranging and monitoring finance: a typical residential retrofit may involve capital expenditure of 5,000–30,000 Euro, and even a significant industrial efficiency project may be only 1–5 million Euro, small by the standards of project finance, where transaction costs such as legal fees, technical due diligence, loan origination, monitoring, and reporting are largely fixed regardless of project size. Consequently, high per-unit transaction costs make small projects uneconomical for commercial finance unless subsidized or aggregated to reach a minimum viable size (EEFIG, 2015).

The small-project problem is compounded by market fragmentation: the energy efficiency market is not a single market, but a collection of many heterogeneous micro-markets differentiated by sector, building type, technology, geography, and ownership structure. This heterogeneity makes it difficult to develop standardised financial products, build portfolios with predictable risk-return characteristics, and attract investors who lack specialised technical knowledge (Bullier and Milin, 2013). Market fragmentation also undermines the development of the data infrastructure needed to support robust risk assessment. In a mature financial market, lenders rely on large historical datasets to model default probabilities; in the energy efficiency finance market, such datasets are largely absent, forcing lenders to rely on worst-case assumptions that drive up the cost of capital (Andaloro et al., 2022).

3.3 LENDER RISK AVERSION AND INFORMATION ASYMMETRIES

Commercial banks and other institutional lenders have historically exhibited a marked reluctance to lend against energy savings. Unlike conventional property-secured lending, where lenders take a charge over a physical asset, lending against future energy savings is secured

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against a future stream of cost avoidance, a form of security that is less familiar, harder to value, and more difficult to enforce than traditional collateral, producing an 'unfamiliarity premium': lenders demand higher interest rates, shorter loan tenors, or additional conventional collateral to compensate for uncertainty they lack the tools to quantify properly (Cao et al., 2011). Surveys of European financial institutions have identified internal technical capacity and the absence of standardized methods for evaluating energy savings as major barriers to scaling energy-efficiency lending (EEFIG, 2015).

Information asymmetries pervade the energy efficiency market. Prospective investors typically lack reliable information about the current energy performance of their buildings or equipment, the available retrofit options, and the track record of contractors and technology suppliers (Giraudet, 2020). From the lender's perspective, a key information asymmetry concerns the credibility of projected energy savings ex-ante and the verification of realised savings ex post (Hill, 2019). While protocols such as the International Performance Measurement and Verification Protocol (IPMVP) exist, the lack of widespread standardised application in financial underwriting limits banks' ability to systematically lend against future energy savings cash flows (Bertoldi and Kromer, 2006).

4. TRADITIONAL PUBLIC FINANCING: SUBSIDIES, GRANTS, AND FISCAL INCENTIVES

A number of well-established financial mechanisms have supported energy efficiency projects, particularly residential building renovations and efficient equipment such as heat pumps (Bertoldi et al., 2021a), including grants and subsidies, fiscal incentives, and subsidised loans. Grants and subsidies directly reduce the upfront capital burden and have been widely implemented in EU Member States, but their effectiveness is constrained by limited public budgets, administrative complexity, transaction costs, and insufficient targeting (Valentová et al., 2018), and grant-based schemes may lack long-term sustainability, generating stop-start investment patterns tied to public funding cycles.

Fiscal measures for building renovations, including income tax deductions and property tax reductions linked to energy efficiency improvements, represent another commonly deployed instrument, aiming to reduce the net cost of renovation for property owners and incentivise investment without requiring direct upfront public expenditure. Their design and uptake vary significantly across jurisdictions, and tax-based incentives may disproportionately benefit higher-income households with sufficient tax liability and capital for the initial investment, raising concerns about equity and distributional impacts. These instruments have been implemented for more than a decade in countries such as Italy and France (Risch, 2020).

Subsidised public loans, typically provided by national or regional development banks at below-market rates with extended maturities, constitute a further pillar of traditional financing, enabling end-users to spread renovation costs over time and leverage private capital. The German KfW Energy Efficiency Programme is the most extensively evaluated example: independent assessments find benefit-cost ratios of 2:1 to 4:1 when employment, health, and energy security co-benefits are included alongside direct savings (Kuckshinrichs et al., 2010), and comparable programmes exist across Europe through national promotional banks such as BPI France, CDP in Italy, and BGK in Poland. Nevertheless, access depends on borrowers' creditworthiness, and risk assessments may exclude low-income or high-risk borrowers.

5. CARBON TAXES, ETS REVENUES, AND PUBLIC CO-FINANCING

A crucial but often underexploited source of public finance for energy efficiency is the revenue generated by carbon pricing instruments, specifically national carbon taxes and the auctioning of allowances under emissions trading systems, e.g. the European Union Emissions Trading System (EU ETS). Carbon pricing creates a double dividend: it directly raises the financial return on energy efficiency investments by increasing the effective cost of energy consumption for end-users, while simultaneously generating public revenue that can be earmarked for efficiency programmes, including projects targeted at households in energy poverty, thereby combining climate and social equity objectives (Wiese et al., 2020). This makes carbon pricing revenues a particularly powerful instrument for addressing the distributional dimensions of

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the energy transition, since the regressive incidence of higher energy prices can be partially offset by directing revenues to support low-income households with efficiency upgrades that permanently reduce their energy expenditure.

Under the EU ETS, the carbon price has risen from below EUR 10 per tonne in 2017 to levels exceeding EUR 60–80 per tonne in recent years, generating cumulative auction revenues of over EUR 175 billion across member states by 2023. The Innovation Fund and Modernisation Fund, established under the revised EU ETS Directive, channel a defined share of these revenues toward low-carbon and energy efficiency investments, prioritising building renovation, district heating efficiency, and industrial process improvements in ten lower-income member states. The Social Climate Fund, introduced under the Fit for 55 package with revenues from the new ETS2 covering buildings and road transport (Günther et al., 2026), supports low-income households and vulnerable micro-enterprises with efficiency upgrades and fuel switching. National carbon tax revenues, such as France's carbon component in domestic energy taxes or Sweden's long-standing carbon tax, have similarly been partially channelled to programmes including MaPrimeRénov' in France and renovation grants in Sweden.

Beyond the direct revenue effect, carbon pricing strengthens the business case for private investment by reducing the payback period of retrofit measures in proportion to the carbon intensity of the energy saved. Modelling studies consistently find that a carbon price of EUR 50–100 per tonne CO_2 is sufficient to bring a large share of currently sub-economic building retrofit measures into positive net present value territory, converting a financing gap into a financing opportunity without direct public expenditure (Lou et al., 2022). The challenge is ensuring price signals are credible, stable, and long-term enough to influence investment decisions with 10–20 year payback periods, requiring legislated commitments with clearly defined price trajectories, as in the UK's carbon price floor and the EU ETS reform's market stability reserve, that are robust to short-term political pressure; where credibility is weak, private investment responds less than the price level alone would predict.

6. ENERGY SERVICE COMPANIES AND ENERGY PERFORMANCE CONTRACTS

For the non-residential sector, Energy Service Companies (ESCOs) are a major enabler of private financing for the renovation of existing buildings, in particular in the public sector, offering energy performance guarantees that increase investors' confidence in energy efficiency projects (Febranzah and Krisprimandoyo, 2025). Under an Energy Performance Contract (EPC), the ESCO finances, designs, installs, and maintains efficiency improvements in exchange for repayment from realised energy savings over a defined contract period. The defining characteristic is the performance guarantee: the ESCO contractually guarantees that a specified level of energy savings will be achieved, transferring performance risk from the client to the ESCO (Bertoldi et al. 2006).

The ESCO EPC model is analytically distinctive because it addresses several financing barriers simultaneously. The performance guarantee directly addresses lender risk aversion: instead of lending against uncertain future energy savings, the financier lends against the ESCO's contractual obligation, a credit risk that can be assessed using conventional corporate credit analysis (Sorrell, 2007), while the ESCO's technical expertise addresses information asymmetry. In the public sector, EPCs offer a further advantage: where balance sheet constraints prevent direct capital expenditure, the EPC structure can be designed as an operating rather than capital expenditure, enabling efficiency investment that would otherwise be blocked by budget rules. The global ESCO market has expanded substantially over the past decade, rising from approximately USD 39 billion in annual project value in 2015 to more than USD 42 billion in 2025 (IEA, 2025).

Notwithstanding its analytical attractions, the ESCO EPC model faces significant practical limitations. The most pervasive is transaction cost: a fully specified EPC requires substantial legal, technical, and financial advisory input, which for small projects below 500,000 Euro can represent a prohibitive share of total project value. Several EU member states have responded with standardised EPC procurement templates and framework agreements that significantly reduce transaction costs, with promising results in France, Germany, and Belgium. A second limitation is dependence on a sophisticated, competitive ESCO sector, which in many markets, particularly in some European countries and most developing economies, remains nascent, insufficiently capitalised, and lacking the technical depth to operate at scale.

The financing of ESCO operations themselves adds another layer of complexity, since ESCOs operating under guaranteed savings contracts must finance upfront installation costs from their own balance sheets or through project finance arranged against the savings guarantee, and smaller ESCOs frequently lack the balance sheet capacity or credit history to access project finance on competitive terms. Several EU member states have responded with dedicated ESCO revolving funds, capitalised by public development banks or European structural funds, that provide below-market bridge financing, while bundling multiple small ESCO projects into a single larger facility, analogous to the aggregation mechanisms described in Section 11, can similarly improve project finance economics by spreading fixed costs across a portfolio.

7. PAY-AS-YOU-SAVE AND ON-BILL FINANCING

On-bill financing, also known as Pay-As-You-Save (PAYS), is an innovative financing model allowing repayment of residential renovation investments through utility bills rather than conventional loan instalments (Johnson et al., 2012). By linking repayment to the property's energy meter, such schemes can improve repayment security and align debt service with realised energy savings, enhancing household cash flow. The critical innovation compared to conventional loan financing is the repayment vehicle: attachment of the obligation to the energy meter or energy account rather than to the individual customer. Because non-payment of energy bills triggers supply disconnection and therefore creates strong payment incentives, the effective default risk on PAYS repayments is lower than on conventional consumer loans, and because the obligation transfers to the next occupant when a property changes hands, the barrier of anticipated mobility is eliminated. Bianco et al. (2022) further develop four adaptable business models for implementing on-bill schemes, ranging from standard on-bill financing and repayment models to more innovative structures such as a Special Purpose Vehicle and Master Servicer approach.

Such performance-based reward of verified, metered energy savings better aligns incentives with policy outcomes than traditional upfront subsidies. Analysis of eleven real-world cases shows that smart metering, robust measurement methodologies, stakeholder collaboration, and flexible payment structures are essential to scaling these programmes. The PAYS system enables utilities to fund residential energy upgrades as revenue-generating assets rather than cost centres: a study of Ouachita Electric's HELP PAYS® program showed 369 homes saving over 1.1 million kWh annually, with a $531,900 net present value, with subsequent programme reforms boosting savings by 42% (Bickel et al., 2022).

Nevertheless, implementation depends on regulatory frameworks that permit utilities to act as financial intermediaries and manage associated risks (Johnson et al., 2012). The UK's Green Deal programme, launched in 2013 and shut down in 2015, provides an extensively documented case study of how PAYS can fail when poorly designed, with key flaws including interest rates set significantly above savings, overly complex application processes, and poor consumer understanding of the product. The fundamental tension in PAYS design is between the 'golden rule' (repayments must not exceed savings) and the reality of energy savings uncertainty: if projected savings prove optimistic due to installation quality, occupant behaviour, or weather variation, the golden rule can be violated in practice (Rosenow and Eyre, N., 2016), requiring either conservative savings assumptions or robust post-installation monitoring and financial reserves.

8. PROPERTY-ASSESSED CLEAN ENERGY (PACE) FINANCING

Property tax-based financing, including the Property Assessed Clean Energy (PACE) model, represents another innovation for building renovation. Under this mechanism, renovation costs are repaid via an additional property tax assessment attached to the building rather than the individual owner (Liaw, 2024), directly addressing the split incentive problem, particularly in rental markets, while allowing financing obligations to transfer upon sale of the property (Kirkpatrick and Bennear, 2014). In the United States, where PACE was first authorised in

California in 2008, the residential PACE market reached approximately USD 2.8 billion in annual financing by 2022, and Commercial PACE has grown rapidly, with programmes active in 35 states (PACENation, 2023). The property tax collection mechanism provides an efficient repayment channel, with collection rates typically exceeding 97%, far above consumer loan repayment rates, enabling PACE to serve a wider credit spectrum.

While promising in theory, adoption of such mechanisms in the EU remains limited and would require significant legal and regulatory adaptation. The primary concern in markets where PACE is established relates to consumer protection: because PACE assessments carry a senior lien on the property, homeowners who cannot maintain repayments face property tax delinquency and ultimately foreclosure, a more severe consequence than defaulting on an unsecured loan, and regulators in the United States have raised concerns about aggressive marketing to vulnerable households (Taylor and Knuth, 2025). A second complication is mortgage market resistance: PACE's senior lien status reduces recovery values for first mortgage lenders, leading government-sponsored mortgage enterprises to decline to purchase mortgages on PACE-encumbered properties in certain jurisdictions (Rose and Wei, 2020). In the European context, the 'Energiesprong' model pioneered in the Netherlands achieves a similar economic outcome through a different legal structure, attaching energy performance guarantees to long-term lease modifications rather than property tax liens (Micelli et al., 2025).

9. GREEN MORTGAGES AND ENERGY EFFICIENCY MORTGAGE INITIATIVES

Energy efficiency mortgages, which incorporate energy performance criteria into mortgage lending practices, have been offered by an increasing number of financial institutions in recent years. By offering preferential loan conditions, lower interest rates, higher loan-to-value ratios, or extended tenors for energy-efficient buildings or qualifying renovations, green mortgages seek to integrate energy performance into property valuation and credit risk assessment. The financial logic is that energy-efficient buildings have lower running costs, reducing default risk, and retain or enhance value more reliably as energy performance regulations tighten. These instruments have the potential to channel substantial private capital into residential building renovation markets (Dell'Anna et al., 2022), although they may be better suited to high-income households (Rochlitz and Hagist, 2026).

The Energy Efficiency Mortgage Initiative (EEMI), launched by the European Mortgage Federation-European Covered Bond Council in 2018, has been a significant catalyst for green mortgage market development in Europe: by the mid-2020s, a growing number of European lenders had introduced green mortgage products, although the segment remained a relatively small share of total mortgage markets. The EeMAP (Energy efficient Mortgages Action Plan) project demonstrated that mortgages on energy-efficient properties exhibit systematically lower probability of default and lower loss given default than the overall mortgage portfolio, strengthening the case for regulatory capital relief for green mortgage portfolios and providing an empirical basis for incorporating energy performance into mainstream bank credit risk models (Hartenberger et al., 2017).

However, green mortgages depend critically on robust energy performance data beyond the energy performance certificate (EPC), reliable measurement and verification systems, and close cooperation between financial institutions and technical experts (Dell'Anna et al., 2022). EPCs in their current form are often an imperfect basis for mortgage pricing, since ratings may diverge from actual energy consumption and are derived using heterogeneous methodologies across EU member states (Cozza et al., 2020), so recent research and policy initiatives emphasise linking green mortgage conditions to verified renovation outcomes and improving interoperable building-energy data infrastructure.

10. WHITE CERTIFICATES AND FEED-IN TARIFFS FOR ENERGY SAVINGS

10.1 WHITE CERTIFICATE SCHEMES

National energy efficiency obligations and white certificate schemes have supported energy efficiency projects with private capital, often raised through energy tariffs (Chlond et al., 2023). In the typical policy architecture, energy companies, such as retailers or distribution companies, are subject to mandatory energy savings obligations: they must deliver or procure a minimum volume of certified energy savings within a defined period, or face financial penalties. Companies that exceed their obligations can sell surplus white certificates to those that fall short, creating a market price for verified savings that tends to favour the most cost-effective efficiency opportunities, since obligated parties will naturally seek out the cheapest savings (Bertoldi and Rezessy, 2008). White certificate schemes have been implemented in Italy (since 2005) (Bertoldi et al, 2010), France (as 'Certificats d'Economie d'Energie', since 2006), the UK (as the Energy Company Obligation) (Archer-Brown and Rosenow, 2026), Spain and Poland, and are now partly mandated across EU member states by the Energy Efficiency Directive (European Parliament and Council, 2023; Fawcett et al., 2019).

France's *Certificats d'Économies d'Énergie* (CEE) scheme, the largest European energy-efficiency obligation by certified volume, has generated more than 4,000 TWh cumac of certified savings since 2006. Annual expenditure is estimated at approximately EUR 3–5 billion, financed by obligated energy suppliers and recovered through energy tariffs rather than direct public expenditure (Ministère de la Transition écologique, de l'Aménagement du territoire et de la Décentralisation, des Transports, de la Ville et du Logement, 2026). This creates a de facto cross-subsidy from all energy consumers to those receiving efficiency measures. The main concerns relate to additionality and measurement: studies find evidence of free-ridership, where companies claim certificates for savings that would have occurred anyway, and of gaming favourable baseline assumptions (Sorrell et al., 2009), with strengthened M&V standards as the primary policy response. Nonetheless, white certificate schemes represent one of the few instruments capable of deploying energy efficiency finance at a scale comparable to large public programmes, without direct budgetary expenditure (Giraudet and Finon, 2015).

10.2 FEED-IN TARIFFS FOR ENERGY SAVINGS AND PAY-FOR-PERFORMANCE (P4P)

Another innovative concept is the application of feed-in tariff logic to energy savings: end-users would receive remuneration proportional to verified energy savings over a period of time (Bertoldi et al., 2013; Eyre, 2013), directly analogous to the renewable energy feed-in tariff, where a savings FiT pays building owners or industrial operators a guaranteed price for every verified kilowatt-hour saved rather than for technology investment, avoiding the moral hazard of the rebound effect and converting efficiency savings into a predictable, bankable revenue stream analogous to those underpinning project finance for renewable energy.

While discussed in the literature (Bertoldi et al., 2013; Eyre, 2013), this concept entails significant administrative complexity and requires standardised, credible monitoring frameworks. The primary barrier is measurement: unlike renewable generation, which is directly metered, energy savings are counterfactual and must be estimated, introducing uncertainty that complicates programme design, although advanced metering infrastructure and machine learning-based baselining are making this increasingly tractable. Pilot implementations in German and Austrian municipalities have shown that a savings FiT can attract commercial bank project finance for residential retrofit on terms comparable to solar PV financing, but broader adoption requires resolving these measurement and market design complexities.

Pay-for-performance (P4P) schemes are a related innovation, particularly in the building sector, where uncertainty in projected savings often constrains capital deployment. Unlike conventional subsidy schemes that provide upfront payments based on ex ante engineering estimates, P4P mechanisms link financial remuneration to verified energy savings measured ex post against a defined baseline, shifting performance risk from public funders or utilities to project developers and creating stronger incentives for high-quality implementation (Tzani et al., 2022). Effectiveness depends on robust measurement and verification protocols, baseline normalisation, and transparent contracts; deployment remains challenged by transaction costs, data availability, and the complexity of attributing savings under dynamic operating conditions (Tzani et al., 2023). The United States has pioneered P4P models, particularly through utility-led measured-savings procurement in California, in which utilities compensate programme administrators based on verified avoided energy use rather than deemed savings estimates, demonstrating potential to improve accountability and mobilise private capital while revealing challenges around baseline setting and savings persistence. In Europe, the Horizon 2020-funded SENSEI Project tested the integration of P4P principles with energy performance contracting, aiming to treat verified savings as a tradable resource and facilitate third-party financing for building retrofits.

11. CROSS-CUTTING ENABLERS: DE-RISKING, AGGREGATION, AND SECONDARY MARKETS

11.1 DE-RISKING THROUGH GUARANTEES AND FIRST-LOSS INSTRUMENTS

De-risking mechanisms play a critical role in mobilising private capital for energy efficiency investments by mitigating the real and perceived risks that deter private financiers. Guarantee instruments such as partial credit guarantees or first-loss facilities, reduce lender exposure to performance or repayment default, thereby lowering the cost of capital and enhancing the bankability of energy efficiency projects (Loureiro et al., 2020).

Public guarantee schemes are widely used to address financing barriers by reducing lender exposure to perceived technical and credit risks. Under a partial credit guarantee, a public institution such as the European Investment Bank or a national green investment bank covers a predefined share of lender losses in the event of borrower default, often through first-loss coverage on a loan portfolio, shifting the risk profile of energy efficiency lending to one compatible with standard credit risk frameworks. Because guarantees constitute contingent liabilities rather than direct expenditures, they can mobilize significant private lending with relatively limited public capital, particularly where realised default rates remain below ex ante assumptions (Honohan, 2010). In practice, national green investment banks often implement these mechanisms through portfolio-level structures in which the public institution provides the guarantee and technical due diligence support while commercial banks retain customer acquisition, origination, and servicing, a division of labour that reduces transaction costs and positions public actors as risk mitigators rather than competitors to private finance.

First-loss facilities are a common blended finance mechanism in which public or concessional capital absorbs the initial tranche of losses within a structured financing vehicle, thereby improving the risk-return profile for private investors occupying senior positions in the capital stack. By subordinating public funds, these structures transfer downside risk away from commercial lenders and can enable financing of projects otherwise too small, heterogeneous, or technically uncertain for conventional investment criteria, particularly relevant for aggregating distributed retrofit projects, though effectiveness depends on careful calibration of the subordinated tranche. Empirical evidence from European initiatives such as the Private Finance for Energy Efficiency (PF4EE) instrument, as well as various emerging market climate funds, indicates that this structure consistently achieves mobilization ratios of private capital per unit of public support ranging from 4:1 to 8:1. The EIB's complementary 'ELENA' (European Local Energy Assistance) programme provides technical assistance grants to help public bodies develop portfolios of energy efficiency projects eligible for EIB financing, subsidising project preparation costs otherwise prohibitive for smaller municipalities.

Performance risk insurance, covering the gap between projected and realised energy savings, is emerging as a complementary instrument to conventional credit guarantees, protecting against underperformance of installed measures and thereby reducing uncertainty in projected cash flows and lowering the risk premium applied by financiers. In Europe, several insurers and market intermediaries have developed standardised energy savings insurance products for EPC and PAYS portfolios, supported by analytical work through the Energy Efficiency Financial Institutions Group (EEFIG). However, underwriting such products requires reliable actuarial evidence on realised project performance, creating a dependency on large-scale, high-quality operational datasets; initiatives such as the De-risking Energy Efficiency Platform, developed with support from the European Commission, aim to address this barrier by aggregating standardised project-level performance and financial data.

11.2 PROJECT AGGREGATION

The small size and heterogeneity of individual energy efficiency projects is one of the most structurally intractable barriers to attracting institutional capital. Project aggregation, the

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bundling of multiple small projects into portfolios of sufficient size and homogeneity to support standardised financing, securitisation, or capital market issuance, is the primary mechanism for overcoming this barrier (Nicolas and Molina-Costa, 2021), achieved through several institutional models. One-stop shops (OSSs), which provide integrated technical, financial, and administrative assistance to households willing to renovate, can reduce transaction costs, address informational barriers, and increase consumer confidence (Donati and Copiello, 2023; Bertoldi et al., 2021b); by managing the entire renovation journey from energy audit through financing arrangement to post-installation monitoring, OSSs effectively aggregate demand and create project pipelines of sufficient scale for institutional finance.

Community energy renovation programmes, in which a neighbourhood, housing association, or municipality coordinates the simultaneous retrofit of a large number of buildings, achieve aggregation benefits through collective action. The 'Energiesprong' model in the Netherlands, replicated in France, Italy, and the United Kingdom, aggregates social housing retrofits into bulk procurement contracts that reduce technology costs, enable standardised financing structures, and provide the scale required for institutional investment. Aggregation platforms, digital marketplaces connecting project developers with investors and matching standardised project data to financing templates, are a more recent innovation that reduces the relational costs of aggregation, though they remain in early stages of development in most markets.

11.3 SECONDARY MARKETS AND SECURITISATION

A critical condition for scaling energy efficiency finance to the levels required for decarbonisation is the development of liquid secondary markets through which financial institutions can refinance, transfer, or securitise portfolios of energy efficiency loans. As long as such loans remain on bank balance sheets as relatively illiquid assets, lending expansion is constrained by capital adequacy requirements, portfolio concentration limits, and internal risk allocation frameworks. Securitisation addresses this constraint by pooling underlying loans and issuing tradable securities backed by their expected repayment streams, recycling capital to originating lenders and expanding their capacity for continued origination, a mechanism central to the growth of residential mortgage, auto loan, and consumer credit markets, with similar conditions progressively emerging in the energy efficiency sector as portfolio size, data quality, and contractual standardisation improve.

The most advanced secondary-market instruments in this field are green covered bonds and asset-backed securities linked to energy-efficient mortgage portfolios, with European issuances by institutions such as Obvion and Münchener Hypothekenbank demonstrating growing institutional demand for energy-linked fixed-income assets. Market development has been supported by standardisation efforts under the Energy Efficient Mortgages Initiative, which promotes harmonised energy performance metrics, data templates, and disclosure practices to improve investor confidence in portfolio quality. Consistent collection of primary-loan performance data is a prerequisite for such markets, as transparent datasets reduce information asymmetries and enable more accurate pricing of securitised assets.

The European Investment Bank Group has significantly expanded its guarantee-based instruments for energy efficiency, reinforcing its role as the principal EU public financial intermediary for addressing the investment gap: in 2025 the EIB financed approximately EUR 7.9 billion in such projects within the EU, delivered substantially through the InvestEU programme, which combines an EU budget guarantee of EUR 26.2 billion with EIB Group implementation and an expected mobilisation effect of at least EUR 372 billion in additional investment. The EIB increasingly deploys guarantee instruments supporting balance-sheet optimisation by partner banks, including synthetic securitisation structures guaranteeing mezzanine risk tranches of loan portfolios, freeing regulatory capital for originating institutions and facilitating the expansion of green lending, particularly relevant for scaling distributed residential retrofit finance where individual loans are small but can achieve institutional scale through aggregation.

The European Investment Fund complements these activities through guarantee products for SME and distributed project financing, including mechanisms supporting energy-as-a-service business models, allowing lenders to finance service contracts repaid from achieved energy savings and broadening access to finance for smaller projects below standard transaction

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thresholds. Across these instruments, leverage ratios vary by structure but frequently exceed several multiples of committed public capital, confirming guarantees as among the most capital-efficient instruments for mobilising private investment in energy efficiency.

12. COMPARATIVE ASSESSMENT AND POLICY FRAMEWORK

The preceding analysis demonstrates that each financing instrument addresses a different subset of the barriers identified in Section 3. Capital grants and subsidies primarily address the upfront capital barrier but do little to resolve split incentives, information asymmetries, or lender risk aversion. Their principal strength is their directness and political legibility they are easy for beneficiaries to understand and act upon, but their fiscal cost and limited long-term sustainability constrain their scale. Concessional public loans similarly address the capital cost barrier but depend on borrower creditworthiness, limiting reach to lower-income and higher-risk actors.

Table 1 provides a structured summary of how each instrument maps to the primary barriers identified in Section 3, allowing direct comparison across the instrument portfolio. A • denotes a primary effect; a (•) denotes a secondary or partial effect.

INSTRUMENT	UPFRONT CAPITAL	SPLIT INCENTIVES	INFORMATION ASYMMETRY	LENDER RISK AVERSION	SMALL PROJECT/ TRANSACTION COSTS	DEMAND-SIDE ECONOMICS
Grants & Subsidies	•	–	–	–	–	(•)
Concessional Loans	•	–	–	(•)	–	(•)
Carbon Taxes/ETS Revenues	–	–	–	–	–	•
ESCO/EPC	•	(•)	•	•	–	–
PAYS/On-Bill Financing	•	(•)	–	(•)	–	–
PACE Financing	•	•	–	(•)	–	–
Green Mortgages	•	–	•	•	–	–
White Certificates	•	–	–	–	–	•
Energy Savings FiTs Pay-for-Performance programmes	–	•	–	–	–	•
De-Risking Instruments	(•)	–	(•)	•	–	–
Project Aggregation/OSSs	–	–	•	–	•	–
Secondary Markets/Securitisation	•	–	(•)	•	(•)	–

Table 1 Mapping of financing instruments to primary market barriers. • = primary effect; (•) = secondary/partial effect; – = not primarily addressed. Barriers correspond to those identified in Section 3.

Carbon taxes and ETS revenues address the demand-side economics of efficiency investment while generating public revenue for targeted programmes, but depend on credible, stable price signals; their distributional impact depends on how revenues are recycled, with targeted renovation support for low-income households the most progressive option. ESCO EPCs simultaneously address performance risk, information asymmetry, upfront capital, and, in some structures, the split incentive, but face high transaction costs that limit their reach beyond the commercial and public sector and depend on a mature ESCO sector absent in many markets. PAYS resolves the capital constraint and mobility problem but requires energy company cooperation and accurate savings projections. PACE resolves capital, tenor, and mobility barriers but creates consumer protection risks and faces mortgage market resistance limiting its applicability in European contexts without significant legal adaptation.

Green mortgages represent a particularly promising pathway for channelling the scale of private capital in mortgage markets, the single largest asset class in most developed economies, toward building energy efficiency, though this requires robust, standardised building energy performance data and a regulatory environment that makes future performance requirements credible. White certificates mobilise private capital at scale without direct public expenditure but face additionality concerns and gaming risks requiring strong M&V governance. Energy savings FiTs and Pay-for-Performance programmes offer elegant incentive alignment and direct

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measurability of outcomes but are constrained by measurement complexity and regulatory design challenges. De-risking, project aggregation, and secondary market development are enabling conditions rather than stand-alone instruments: they amplify the effectiveness of all others by reducing transaction costs, mobilising capital, and recycling financing capacity.

No single financing mechanism can overcome the multifaceted barriers to energy efficiency investment; instead, a diversified and context-sensitive portfolio of instruments is required, embedded within coherent regulatory frameworks (Bertoldi et al., 2021a). Evidence from the most successful national systems, Germany, France, the Netherlands, Italy, consistently shows that effective financing architecture requires not just instrument selection but instrument sequencing: starting with direct public financing and technical assistance to demonstrate project viability and build market capacity; transitioning to de-risking instruments that mobilise private capital once a performance track record exists; and ultimately enabling market-based instruments and secondary market development to operate at scale with minimal ongoing public support, outcomes typically measured in decades rather than years.

13. CONCLUSIONS

The energy efficiency investment gap is large, persistent, and consequential for both climate and economic objectives. It is not primarily a technology gap: the technologies needed to improve efficiency in buildings, industry, and transport are largely mature and commercially available. It is fundamentally a financing gap, rooted in a well-investigated set of market failures, structural barriers, and institutional limitations that interact to make energy efficiency investment difficult to structure, fund, and execute through conventional financial channels. These barriers, upfront capital requirements, small project sizes, market fragmentation, lender risk aversion, split incentives, and information asymmetries, are mutually reinforcing and cannot be addressed by any single instrument or policy measure.

This paper has examined the principal financing instruments developed to address these barriers, from traditional public financing tools through progressively more market-oriented mechanisms, and the cross-cutting enablers essential for achieving scale. Traditional tools, grants, subsidies, tax incentives, and concessional loans, provide a necessary foundation but face fiscal constraints and limited reach. Carbon taxes and ETS revenues are an underexploited complement, improving the economics of private efficiency investment while generating revenues directable toward those most in need, such as households facing energy poverty. Market-based instruments, ESCO EPCs, PAYS, PACE, green mortgages, white certificates, and energy savings FiTs and Pay-for-Performance programmes, each address specific barrier configurations and, when properly designed and governed, can mobilise private capital at scale with limited public financing. De-risking, project aggregation, and secondary market development are not instruments in the same sense but enabling architectures that allow individual instruments to operate at the scale required.

On the basis of the analysis and the instrument–barrier mapping in Table 1, five concrete recommendations emerge for policymakers, financial institutions, and researchers. First, governments should adopt layered national financing strategies combining direct public support (grants, concessional loans) with de-risking tools (guarantees, first-loss facilities) and market-based mechanisms (ESCO EPCs, PACE, white certificates, Pay-for-Performance programmes), sequenced to progressively crowd in private capital as market capacity develops; the appropriate mix depends on national context and the maturity of local ESCO and financial sectors. Second, investment in data infrastructure, standardised building energy performance registers, robust M&V frameworks building on the IPMVP, and transparent post-project performance data, should be treated as a foundational public good: without it, de-risking instruments cannot be priced, secondary markets cannot develop, and green mortgages cannot be effectively underwritten. Third, the EU and member states should accelerate enabling legislation for PACE-equivalent instruments, on-bill financing, and energy savings feed-in tariffs/Pay-for-Performance programmes, removing barriers that have prevented these proven concepts from scaling across Europe. Fourth, carbon pricing revenues from the EU ETS and national carbon taxes should be ring-fenced and deployed progressively toward deep renovation support for low-income households and organisations that cannot access private finance, rather than absorbed into general fiscal revenues. Fifth, future research should focus on the comparative performance of national financing architectures, the distributional impacts of revenue recycling strategies, and the conditions under which secondary market development becomes self-sustaining. An effective financing architecture is, in sum, a portfolio rather than a single instrument: the most successful national systems combine complementary instruments within a coherent regulatory environment, such as the EED and the Energy Performance of Buildings Directive (EPBD; European Parliament and Council, 2024), sequencing public intervention to progressively crowd in private capital. Given the scale of the opportunity and its centrality to the EU's 2030, 2040 and 2050 climate objectives, this investment in policy architecture is among the most consequential that governments and institutions can make.

ADDITIONAL FILE

The additional file for this article can be found as follows:

- **PowerPoint Slides.** PowerPoint Slides relating to this article. DOI: https://doi.org/10.66506/essp.3-176-26.s1

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AUTHOR AFFILIATIONS

Paolo Bertoldi orcid.org/0000-0002-2797-7941
Independent expert, Luxembourg

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