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Achieving greater residential energy savings through optimised subsidy allocation

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EXTENDED ABSTRACT

Energy efficiency subsidies play a key role in reducing residential energy consumption, but their impact can be limited by inefficient allocation. This study introduces a multi-method framework to improve subsidy distribution by identifying retrofit strategies that maximise energy savings while staying within budget constraints. The framework is applied to a renovation subsidy scheme targeting single-family houses in Croatia. The findings offer valuable insights to improve subsidy effectiveness and accelerate building decarbonisation.

Introduction / background

In the context of increasing energy efficiency to achieve the climate objectives set by the European Union (EU), the revised Energy Efficiency Directive almost doubled the obligation of Member States from 0.8% to approximately 1.5% for the period 2024-2030, progressively increasing from 1.3% in 2024 to 1.9% in 2030 and beyond (European Parliament, 2023). Given that buildings account for up to 40% of the total energy consumption in the EU and more than a third of the total greenhouse gas (GHG) emissions, improving their energy performance is key to achieving the cornerstone objective of the 55% reduction in emissions by 2030 set in the European Green Deal (Siddique et al., 2022).

In order to deliver on the increased ambition, EU Member States implement a wide range of policy instruments for the building sector ranging from regulatory and behavioural measures to tax exemptions and financial incentives like grants and subsidies. Among these instruments, financial incentives serve as crucial tools for promoting energy retrofitting in buildings, with direct capital grants having a prevalent place across the EU (Bertoldi et al., 2021; Fuchs et al., 2023). Despite the wide deployment of such financial incentives, provided to encourage energy efficiency improvements in the residential sector, their effectiveness on renovations and the subsequent impact on energy savings is questioned in the literature (Studer & Rieder, 2019). This can be partially attributed to the inefficient allocation of subsidies budget due to the lack of consistent distribution criteria, ignoring the effectiveness and final profitability of the measures, including any resulting windfall effect. In this context, many studies have highlighted the need to consider cost-effectiveness and maximisation of energy savings in the design and implementation of national subsidy programmes in order to decarbonise the building stock at the lowest cost for society (Di Pilla et al., 2016; Siddique et al., 2022).

In this work, we address this need by developing an assessment framework for renovation subsidy programmes with the aim of maximising their impact. While often subsidy schemes rely on top – down assessments that might not accurately reflect savings potential, the present framework allows for a granular assessment of retrofit scenarios across diverse building typologies. Furthermore, it provides data-driven and performance-based insights for the subsidy allocation strategy, while taking into account financial constraints. The framework is applied to an incentive scheme implemented in Croatia. The scheme provides subsidies for energy renovations, but the allocation strategy does not incorporate at the moment any cost-effectiveness metrics or energy savings potential assessment.

Methodology

The goal of the study is to develop and apply a comprehensive assessment framework that ensures the optimal allocation of renovation subsidies in residential buildings, with the primary objective of maximising energy savings while adhering to financial constraints. The framework consists of two core components: **(i) a modular bottom-up building simulation model** that is designed to simulate the buildings' energy consumption and **(ii) an optimisation model** designed to allocate subsidies in a way that maximises energy savings. The application considers a €120 million scheme targeting single-family houses that aims to renovate 10,000 houses and achieve annual energy savings of 0.92906 PJ.

Energy Demand Simulation and Retrofit Scenarios

At the core of this study methodology is the Dynamic high-Resolution dEmand-sidE Management (DREEM) model (Stavrakas & Flamos, 2020), which performs bottom-up simulations and provides energy consumption assessment for the different building typologies. Through its different modules, the model incorporates various aspects, including weather data, building characteristics (e.g., building envelope features, heating and cooling systems, etc.), thermal comfort analysis, occupancy profiles and appliances inputs.

To initiate the analysis, the baseline energy performance is established for six different building typologies[1]. Each typology is characterised by key parameters including construction period, climate zone, building geometry, thermal properties of the building envelop, and heating system specifications. Following, different retrofit scenarios are simulated based on the technical requirements of the Croatian incentive. The scheme provides funding for a range of interventions, including full renovations, insulation improvements and energy-efficient heating, ventilation, and air conditioning (HVAC) systems replacement. For each of the scenarios, the energy consumption is being estimated along with the potential energy savings, as well as related costs, ensuring compliance with the financial constraints set by the scheme. The cost estimations of the measures were derived through pertinent literature review and, when appropriate and feasible, supplemented by market-based research.

Optimisation Model for Budget-Constrained Allocation

Traditional subsidy programmes often operate on a first-come, first-served basis, leading to inefficiencies when funds are allocated to projects that provide only marginal energy savings (Turai & Szemző, 2022). This approach may inadvertently favor applicants who are best informed and quicker in applying rather than those whose retrofits would generate the most significant energy savings. To address this, the second key component of this study consists of a multi-step optimisation approach which aims to ensure that the overall subsidy scheme budget is distributed across the residential building stock in a way that maximises energy efficiency gains, by prioritising homes with the highest potential for energy savings. To ensure that the scheme's requirements are met the Croatian building stock is also characterised by energy class.

The optimisation process determines which distribution in renovation scenarios examined per building typology will yield the greatest energy savings, aiming to avoid situations where expensive interventions are funded without delivering proportional energy reductions. Alignment with the scheme's main goals on overall annual savings and the number of renovated houses is also considered.

By integrating energy demand modeling with a structured optimisation approach, this methodology ensures that the subsidy program delivers measurable improvements while maintaining financial sustainability.

Discussion and Conclusions

Subsidy programmes for energy retrofits targeting residential buildings are often designed and implemented without considering distributional criteria. This study proposes and demonstrates the advantages

[1] The data for the six typologies were obtained from materials provided by the Energy Institute Hrvoje Požar within the scope of the Life Programme ENSMOV Plus project.

of the use of an optimization framework for subsidy allocation. The framework aims to maximise energy efficiency within budgetary limits, ensuring that funding is strategically directed toward high-impact renovations. This multi-step optimisation approach offers a replicable model for other EU subsidy programs aiming to achieve higher energy savings in the context of the national and EU climate objectives.

Future research in this area could benefit from examining the cost-effectiveness of each renovation scenario, for instance through estimating the Net Present Value, Internal Rate of Return, or other relevant indicators as well as incorporating a rebound effect when estimating the energy savings resulting from a particular investment. While this study does not consider the socio-economic characteristics of families living in different building typologies, this remains still an important area for further methodological development. Finally, comparing the results of the optimisation model with the current situation of what the scheme delivers could also provide valuable insight for future policy incentives' design recommendations.

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