Problem Identification

The Sustainable Development Goals (SDGs) form a framework to advance human well-being, economic prosperity, and environmental protection in an integrated way, stressing that progress in one goal should reinforce, not undermine, others (United Nations, 2015). Within this agenda, energy systems and the built environment are pivotal because they connect climate mitigation, human security, and urban development outcomes (Nodi, 2025; United Nations, n.d.).

SDGs, climate change and human security

The SDGs are explicitly designed as an indivisible set, with interdependent goals on poverty, health, education, clean energy, sustainable cities, and climate action (United Nations, 2015). SDG 7 (Affordable and Clean Energy) and SDG 11 (Sustainable Cities and Communities) sit at the core of these interlinkages: how societies produce and use energy, and how cities are planned and built, directly shapes health (SDG 3), economic opportunities (SDG 8), Industry, innovation and infrastructure (SDG 9), climate action (SDG 13), and Peace, justice and strong institutions (SDG 16) (Nodi, 2025). At the same time, climate change is already undermining human security, as rising temperatures and more frequent extreme events threaten lives, health, and critical infrastructure (Germanwatch, 2026; United Nations, n.d.; World Meteorological Organization, 2025). Vulnerable countries and communities, which have contributed least to global emissions, are among the most affected by climate-related disasters, which intensifies poverty and displacement and strains basic services (Germanwatch, 2026; United Nations, n.d.).

Energy trends reinforce this urgency. Global energy demand and emissions remain misaligned with pathways that would limit warming in line with the Paris Agreement, despite growth in renewables and efficiency gains in some sectors (Climate Action Tracker, 2025; United Nations, 2025b). Progress towards SDG 7 is uneven: electricity access has expanded, but universal access by 2030 is unlikely - improvements in energy intensity and renewable shares are too slow to meet climate targets (United Nations, 2025b). Moreover, current SDG 7 indicators often rely on national averages and input-focused metrics, which obscures who benefits from energy transitions and how these changes interact with other goals, such as health, gender equality, and reduced inequalities (Nodi, 2025).

Cities, housing and vulnerability

Urban areas concentrate people, economic activity, infrastructure, and emissions, making SDG 11 a key node in the SDG network. Yet many cities face a “triple challenge” of affordability, adequacy, and resilience in their housing and infrastructure. Between 1.6 and 3 billion people are affected by housing affordability problems, and over a billion people live in slums or informal settlements characterized by overcrowding, insecure tenure, and inadequate access to basic services (United Nations, 2025c). Meanwhile, climate change amplifies urban risk: large numbers of city residents are projected to experience more frequent heat extremes and increased flood exposure, while many cities lack sufficient green space and face a substantial financing gap for climate-resilient infrastructure (United Nations, 2025c). These pressures mean that housing and building policies must simultaneously address affordability, resilience, and decarbonization to support SDG 11, SDG 7, and SDG 13 and to not advancing housing policies at the expense of sustainability (Gebara & Laurent, 2022; United Nations, 2025c).

Buildings and energy efficiency as a critical problem

Within this broader context, the buildings sector emerges as a critical intervention point. Globally, buildings account for a large share of final energy use and associated emissions (International Energy Agency, 2025a), while also shaping indoor comfort, health, and the affordability of energy services. Analyses show that improving building energy performance - through better envelopes, high-efficiency heating and cooling, and smarter operation - are one of the most important steps to drive energy efficiency progress in advanced economies (International Energy Agency, 2025a). However, the current pace of improvement, especially in existing building stocks, falls short of what would be required for net-zero-consistent pathways (International Energy Agency, 2025a, 2025b). Poor housing conditions, particularly low thermal efficiency and inadequate building envelopes, increase household energy needs and costs while often failing to provide adequate indoor comfort, thereby raising the risk of energy poverty and reinforcing existing social inequalities (Chen & Feng, 2022).

At the household level, decision-making around building energy efficiency is complex. Research shows that tailored feedback and information can support more sustainable practices (Höpfl et al., 2025), but decisions rely on financial capacity (Volodzkiene & Streimikiene, 2025). People often struggle to understand the energy and cost implications of different building upgrades, appliance choices, and operational behaviors (van den Broek, 2019). From an SDG perspective, this points to a clear problem: buildings are central to achieving climate mitigation, affordable and clean energy, and sustainable cities, yet many households lack accessible, trustworthy guidance to navigate complex efficiency options in a way that aligns their individual decisions with broader sustainable development objectives. Articulating and addressing this decision gap at building level is therefore justified as a concrete, high-leverage contribution to the SDGs.

Socioeconomic Challenges due to high Energy Prices

The post-pandemic economic recovery and the 2022 Russian invasion of Ukraine have triggered a severe surge in global energy prices, leading to historically high inflation rates and a prolonged cost-of-living crisis (Lokshin, Sajaia, & Torre, 2023). This energy-driven inflation has heavily burdened households by drastically increasing utility bills, which exacerbates existing inequalities and substantially raises the risk of energy poverty across Europe and globally (European Commission, 2023; Lawson, 2023). In this context, improving building energy efficiency serves as a highly effective strategy to reduce energy consumption and shield consumers from future price volatility (Calthrop, 2022).

Product Idea Outline

To address the identified problem, we'll propose a ML-powered decision support tool that helps homeowners identify the most impactful steps to improve the energy efficiency of their houses. By providing personalized, ranked recommendations for energy efficiency retrofits - along with estimated investment costs and expected annual bill reductions - the tool empowers households to make cost-effective upgrades, thereby reducing their long-term energy demand, protecting them from market volatility, and alleviating the financial strain caused by soaring energy prices.

The MVP uses a web interface and a FastAPI backend to predict building energy performance from user inputs and then rank retrofit options.

Core idea and data basis

The tool addresses the problem that individual homeowners face complex, fragmented information when deciding how to improve the energy performance of their home, even though building efficiency is a key lever for affordable and clean energy, sustainable cities, and climate mitigation (International Energy Agency, 2025a; United Nations, 2025b, 2025c). Accordingly, the product is not to be understood as a fundamentally new and innovative solution. Its main goal is to make information accessible to people and through that help in facilitating their decision making to take climate action. As its main empirical foundation, the system uses open data from the Carbon & Place project, which provides spatially disaggregated information on housing, energy use, and carbon footprints, including processed domestic Energy Performance Certificate (EPC) data for Great Britain (Morgan, 2025). From these EPC data, the system learns how combinations of basic dwelling characteristics relate to energy performance, enabling user-specific predictions for similar homes.

Technological approach and ML models

The backend follows a two-stage modelling strategy. First, a regularized linear regression model (e.g. Ridge or Lasso) is used as a transparent baseline to predict an energy-performance proxy (such an EPC-aligned rating score) from a compact set of features derived from the Carbon & Place and EPC-summary variables. Second, an XGBoost regressor serves as the main advanced model, reflecting evidence that gradient-boosted trees achieve high accuracy in building energy prediction tasks and capture non-linear interactions between features more effectively than linear models(Guler Kangalli Uyar, Ozbay, & Dal, 2025) .

Architecture and workflow

The user interacts through a webapp (e.g. via Lovable), which provides an input form with a concise set of descriptors aligned with information that can be robustly linked to the training data, such as dwelling type, approximate floor area, construction period, primary heating system, etc. (Morgan, 2025). When the user clicks a button, the frontend sends the form data as JSON to a locally running FastAPI backend.

The FastAPI service exposes an endpoint that:

1. preprocesses the input into the feature format expected by the models,
2. calls the XGBoost model to predict current energy performance (e.g. an approximate EPC-style rating band inferred from the training distribution), and
3. generates a set of predefined and hard-coded retrofit scenarios representing typical improvement steps, such as improved insulation, upgraded glazing, or a more efficient heating system. For each scenario, the relevant features are adjusted to reflect the upgraded state and calls the same model to obtain counterfactual performance, then compares each scenario to the baseline to estimate relative efficiency gains.

The response returned to the frontend includes the predicted baseline performance and rating, a ranked list of measures with impact labels (e.g. high/medium/low impact), and a short explanation of which current features most strongly drive the home's energy demand.

Costs and savings as optional feature

Reliable, granular cost data for retrofit measures are often context-specific and may not be readily available in the Carbon & Place or EPC-derived datasets, so the core decision logic focuses on relative efficiency impact rather than economics. However, the design leaves room for an optional extension: if suitable cost and typical savings data are available - for example, from national retrofit programs or additional databases - the backend can be extended to attach indicative investment ranges and simple payback times to each recommended measure. In that mode, each scenario evaluation would combine predicted energy savings with assumed tariffs and cost ranges to compute annual bill reduction and basic economic metrics, enabling a dual ranking by impact and cost-effectiveness.

Possible future extensions

Several enhancements could increase value beyond the initial version. The model could be retrained or augmented with additional datasets (for example, more detailed EPC tables). The interface could allow users to refine predictions with optional historical energy bills or smart-meter summaries, enabling calibration of the model to actual consumption and occupancy patterns. More advanced explanation features - such as interactive SHAP plots or "what-if" sliders that show how changing single parameters affects performance - could strengthen user understanding and trust in the recommendations. Finally, the tool could integrate policy-specific information, such as links to local incentives, planning guidance, or certified installers, turning the technical recommendation engine into a broader decision-support platform aligned with place-based, SDG-oriented decarbonization strategies.

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