Digital Twins for Positive Energy Districts (PEDs): a decision-support model for energy planning in urban areas

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Abstract As cities lead the transition toward climate neutrality, the development of Positive Energy Districts (PEDs) presents a multidimensional challenge that spans technical, economic, and social dimensions. This study investigates the application of Digital Twin (DT) technology as an integrated decision-support system to guide urban energy planning and policy. We propose a novel methodological framework that combines Cost-Benefit Analysis (CBA) with Multi-Criteria Decision Analysis (MCDA) to evaluate and rank alternative PED implementation scenarios, capturing both monetary and non-monetary impacts on local development.

Building on established practices in environmental and infrastructure decision-making, our approach is tailored to the urban energy context through the dynamic capabilities of a DT. Leveraging the ExPEDite Horizon Europe project, the proposed approach is applied to a district in Riga, the capital city of Latvia, where the DT integrates real-time data on energy consumption, building performance, and user behavior. This integration enables the simulation of alternative retrofit and renewable energy strategies under various financial, environmental, climate and behavioral assumptions.

CBA is employed to evaluate project feasibility and economic returns while MCDA accounts for critical qualitative dimensions such as energy resilience, carbon reduction, and citizen engagement. The two streams are integrated into a hybrid scoring and ranking model, offering an economic decision-support tool for urban stakeholders and policymakers.

The research contributes to emerging debates on the economic valuation of urban energy projects, demonstrating how advanced modeling tools can support evidence-based planning, risk-informed investment decisions, and policy co-design. By facilitating structured trade-offs between financial, environmental, and social objectives, the proposed approach promotes more transparent and participatory energy transition pathways. Additionally, the study addresses the potential for DT-based tools to enhance local governance capacities, inform place-based innovation strategies, and strengthen the territorial capital and resilience of urban systems.