

Decarbonizing Urban Heating Systems: The Impact of Energy Price Signals on Decentralized Household Investment Decisions

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Extended Abstract

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Abstract Summary

Decarbonizing residential heating is essential for achieving climate neutrality in Germany and across Europe. This transition requires the large-scale adoption of low-carbon technologies such as heat pumps, renewable electricity, and district heating. However, most energy system models rely on centralized cost optimization and fail to capture how decentralized household decisions respond to energy price signals.

This study examines how electricity, natural gas, and district heating prices jointly influence household investment decisions and the resulting technology mix in urban heating systems. We develop a multi-actor mixed-integer linear programming (MILP) framework that compares centralized system planning with a decentralized setting in which households optimize investments based on individual economic incentives. The model is applied to residential buildings in Schweinfurt, Germany, and includes key technologies such as heat pumps, gas boilers, rooftop PV, battery storage, thermal storage, and district heating. A systematic sensitivity analysis is conducted across a wide range of energy prices.

The results show that energy price structures strongly shape both technology adoption and decarbonization pathways. Decentralized decision-making leads to higher total system costs but can improve household-level economic outcomes and, in some cases, accelerate electrification. We identify tipping-point behavior: small increases in district heating tariffs trigger rapid shifts toward decentralized technologies, while high electricity prices significantly reduce heat pump adoption, leading to continued reliance on gas-based heating despite carbon pricing.

These findings highlight the importance of cross-price interactions between energy carriers and demonstrate that carbon pricing alone is insufficient to drive decarbonization. Effective policy design requires coordinated pricing across electricity, gas, and district heating to align decentralized investment decisions with system-level climate goals.

Presenting Author Biography

Renu Chaudhary is a doctoral researcher at the Technical University of Applied Sciences Würzburg–Schweinfurt, Germany. Her research focuses on energy system modeling and optimization for the decarbonization of urban heating systems. Her work explores how energy price signals, policy design, and household investment decisions interact to shape sustainable and cost-effective heating transitions.