**Urban Design and Energy Demand Patterns: A Spatial Analysis Using Geolocated Smart Meter Data from UK Households**

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**Abstract** As city become more decarbonised and electrified, understanding how energy demand varies across time and space is increasingly important for effective energy management and planning. Such insights enable targeted infrastructure investments in areas of highest need and supports the design of demand-side strategies that optimize the use of variable renewable energy sources while managing growing peak loads.

While existing research has primarily focused on household-level determinants (e.g. socio-demographics, building characteristics, and appliance ownership) and environmental conditions (e.g. temperature and solar irradiance), growing evidence from urban and transport studies underscores the importance of the urban spatial context. For instance, the built environment, land-use patterns, and transport infrastructure influence human mobility and daily activity rhythms, which in turn shape where and when energy is consumed. Overlooking these contextual factors not only leads to suboptimal energy planning interventions but also constrains the development of systemic demand-side solutions.

This research investigates how urban spatial context influences household energy demand, aiming to inform new demand-side strategies that support urban energy transitions. We use spatial regression techniques to analyse geographic variation and the underlying drivers of household electricity use, with a focus on both physical (e.g. urban density, urban form) and functional (e.g. land-use mix, transit accessibility) urban characteristics. Our analysis draws on a unique dataset that combines georeferenced smart meter data from over 13,000 UK households, detailed household surveys, and spatial context indicators derived from OpenStreetMap.

Our findings demonstrate that urban design characteristics—such as compact vs dispersed, mixed-use vs mono-functional, transit-rich vs car-dependent—significantly affect the synchronization and predictability of household energy demand. These insights underscore the importance of integrating urban spatial context into both demand-side interventions and strategic infrastructure planning. Ultimately, by bridging urban and energy planning, this research offers actionable insights for distribution system operators, policymakers, and urban planners working toward carbon-neutral cities.