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Spatial Disaggregation of Transport Demand in Energy Models: Implications for Equitable Decarbonization Pathways

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Extended Abstract

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Abstract Summary

Achieving net-zero emissions by mid-century requires deep decarbonization of the transport sector, which accounts for 46% of energy-related CO_2 emissions in France. Energy system models are central tools for identifying cost-effective transition pathways, yet conventional approaches rely on aggregated assumptions such as uniform annual mileage or average modal shares that mask critical spatial heterogeneity and introduce systematic biases in policy recommendations. This paper presents a spatially and functionally disaggregated framework for long-term transport decarbonization modelling in France. The methodology integrates three interconnected modules. A Location Module maps population distribution across four zone types (central poles, secondary poles, suburban areas, and rural zones) and projects demographic trajectories up to 2070 under alternative urbanization scenarios. A Social Demand for Mobility Module captures zone-specific modal constraints and trip-distance patterns, enabling the simulation of structural shifts in public transport uptake and active mobility across contexts where such substitutions are feasible. A Vehicle Selection Module built on the TIMES optimization framework determines cost-optimal technology mixes including electric, hydrogen, hybrid, and biogas vehicles under differentiated demand profiles and policy constraints. Results reveal that aggregate models systematically underestimate the affordability trilemma inherent in transport transitions. Three findings are central to the energy economics debate: first, spatial inequalities in transport accessibility make universal electrification mandates economically inefficient and socially regressive for peripheral and rural households; second, subsidy schemes designed without zonal differentiation produce inequitable redistributive effects that disproportionately benefit high-mobility urban dwellers; third, policies such as internal combustion engine bans ignore the structural constraints of populations with limited access to alternatives, risking both social acceptance and implementation failure. The proposed framework demonstrates how disaggregated spatial information can be incorporated into bottom-up energy models without a prohibitive increase in complexity, offering a replicable methodology for equitable and economically sound decarbonization policy design across European contexts.

Presenting Author Biography

Enrico Patanè is an energy systems modeller at Mines Paris-PSL,where he works on the spatial disaggregation of transport demand within long-term energy optimisation frameworks. He holds a Master's degree in energy engineering from Politecnico di Milano and a specialised Master in energy systems optimisation from Mines Paris-PSL. Prior to his current research position,he gained industry experience in long-duration electric storage technologies,which shaped his interest in the interface between technological innovation and energy policy design. His current work focuses on developing modelling approaches for effective policy making in the context of the energy transition.