How Urban Form and Land Use Shapes Energy Emissions? A Data-driven Comparative Study of Seoul

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Abstract Studies of urban energy emissions tend to assume that urban form has the potential to shape human behaviour, driving both human development and technological progress. Previous empirical studies have emphasised the role of urban form typologies in enhancing energy efficiency in the context of urban planning. However, most of these studies focus solely on building-related energy consumption through electricity and gas usage, overlooking other urban emission sources. To better understand the complexity of urban systems regarding energy emissions, this study expands the analytical scope by integrating both urban form and urban function as key components of urban structure typologies.

Specifically, this study investigates how the combination of both urban form and land use contributes to energy-based emissions across neighbourhoods in Seoul. Typologies of urban structure are derived using the Gaussian Mixture Model (GMM) clustering method, based on 18 variables that represent urban geometry, land-use composition, and socio-economic characteristics. These include metrics such as the number of buildings, number of plots, average plot size, Floor Area Ratio (FAR), building coverage, building age, building height, road/pavement area ratio, transit accessibility, population density, household income levels, and ratio of each existing land use (residential, commercial, industrial, infrastructure, green space, waterbody, and vacant). To measure emissions, the study integrates multiple sources of energy-based emissions data in 2021, including electricity and gas consumption, as well as transport-related emissions.

The urban typologies are then used as explanatory variables in four regression models, such as Ordinary Least Squares (OLS), Random Forest (RF), XGBoost, and Spatial Lag Model (SLM), to assess their predictive power in explaining emissions intensity at the neighbourhood level. Among them, spatial regression modelling (SLM) offers improved explanatory power in accounting for spatial autocorrelation effects, particularly in peripheral urban areas where emissions patterns tend to cluster geographically.

This study demonstrates that urban typologies with compact built environments characterised by high-density residential, commercial, and infrastructural land uses are significantly associated with higher energy-based carbon emissions. The emissions show a strong positive relationship with built-up land types, while natural and undeveloped lands exhibit weak to moderate negative correlations. Compact typolo-

gies with greater transit accessibility and vertical development tend to exhibit lower per capita emissions, reinforcing the efficacy of dense, transit-oriented development in mitigating urban carbon output.