Spatial Analysis of the Energy-Transport Vulnerability Index in Greater Urban Communities

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1. Project Summary

The decarbonizing city and transportation have become urgent agendas to fight climate changes in the US. Many urban strategies were initiated to actuate this commitment, e.g., smart energy infrastructure, energy-efficient building design, and alternative fuel vehicles. Envisioning post-carbon urban through these strategies requires an initial assessment of the urban itself, where one important aspect is energy vulnerability in society. Martiskainen et al. (2021) and Robinson et al. (2020) introduced two poverty indexes as new dimensions in describing energy vulnerability in a city, i.e., domestic energy poverty (DEP) and transportation poverty (TP). Energy poverty refers to the ability to attain a level of domestic energy needs. Transportation poverty refers to the ability to attain a level of transport services. Both poverties have direct impacts and are interlinked in achieving low-carbon urban. This project aims to conduct a spatial analysis of the Energy-Transport Vulnerability Index (ETVI) to understand the given urban region's energy vulnerabilities. We leverage open-source databases to collect and curate sociodemographic, environment quality, transportation, and energy consumption data. Then, we evaluate the spatial pattern of ETVI and its implication to urban decarbonization strategies.

2. Urban Adaption/Sustainability Strategies

Methods for reducing the carbon footprint of urban communities and their outlying suburban areas can further exacerbate domestic energy and transportation poverty; therefore, sustainability strategies should be strategically implemented to support the communities equitably while combating climate change (Martiskainen et al., 2021, Robinson & Mattioli, 2020). While domestic energy poverty does not definitively mean transportation poverty, there is a strong correlation between the two indexes: homes that have difficulty paying necessary heating bills would also have a higher likelihood of having difficulty affording transportation costs relative to those who do not have difficulty paying energy bills. Spatial implementation of carbon-reducing strategies and cost redistribution methods can help policymakers locate the vulnerable clusters and not further push residents suffering from domestic energy and transportation poverty deeper into economic depression. Our project will research the effectiveness of the spatial implementation of strategies and analyze the effects of different carbon-reducing strategies on communities with elevated domestic energy and transportation poverty levels.

3. Methodology

3.1 Indicators

The project considers three main groups of indicators, i.e., DEP, TP, and environment quality, and due to interconnected nature, some indicators are attributed to multiple group characteristics. Domestic energy poverty would include the share of energy expenditures of the household income, the total household energy uses, and the accessibility to refueling/recharge infrastructures. Transportation poverty includes three dimensions: exposure, sensitivity, and adaptive capacity (Mattioli et al., 2019). Exposure describes the share of fuel expenditure to the household income. Sensitivity represents mobility's perturbation, decided by the household income. Adaptive capacity refers to the accessibility for the household to alternative transport modes, e.g., transit and walking. Both DEP and TP are additionally characterized by the similar community and household demographics (e.g., income status, minority status, and family with dependents.). Both poverties are interconnected and attributed to these demographic characteristics and can characterize their joint vulnerability. Environment quality is characterized by PM 2.5, NO_2, Urban Heat Island (UHI), Tree Cover, and Public Transit which measure the environment and social inclusion index to existing urban conditions. Combining these with DEP, TP, and demographic characteristics, we can reveal the environment outcome equity and further understand the spatial variability (Data Driven Envirolab [DDE], 2018)

3.2 Data Sources

The data sources could include American Community Survey (ACS), Integrated Public Use Microdata Series (IPUMS), the Smart Location Database (SLD), SimplyAnalytics, US EIA, and National Household Travel Survey (NHTS).

Table 1. Indicators and corresponding data sources.

Indicators	Database
Urban environment and social equity	Urban Environment and Social Inclusion Index
Total household energy consumption	EIA, ACS, NHTS, Meta-analysis (literature)
Accessibility to refuel/recharge infrastructures	EIA, ACS
Exposure (fuel expenditure and income)	SimplyAnalytics, ACS
Sensitivity	ACS
Adaptive capacity	SLD, Open Mobility Data
Household Demographics	ACS, IPUMS

3.3 Scale of Analysis

The scale of analysis would be determined according to the scale of data availability. Ideally, we would like to examine a major urban community and its greater vicinity in the United States. Los Angeles, New York City, and Chicago have relatively complete data sources from the initial review. We plan to use the census tract as a unit to analyze the spatial distribution of DEP, TP, and environment-social equity. Since data quality is a major study limitation, the exact location of the study will be refined based on data accessibility as we continue to explore available data.

3.4 Analysis Approach

We establish the composite EVTI by normalizing the DEP, TP, and environment-social equity indicators using z-score, t-score, or other normalization methods. Next, we compare the spatial distribution of ETVI and urban environment and social equity. We then propose and compare decarbonizing strategies to balance the environmental outcome and energy-transport poverty across urban communities.

4. Results and Expectation

By spatially examining the energy vulnerabilities across society through DEP and TP, an Energy-Transport Vulnerability Index will be formulated to better identify the most disadvantaged individuals and groups due to existing social dynamics and urban energy-transportation form. We expect the ETVI to isolate certain more disadvantaged groups; however, due to the interdependent and dynamic nature of energy-transport vulnerabilities, we cannot speculate which areas will ultimately be classified as more disadvantaged when both DEP and TP are grouped together. Better identification of vulnerable populaces through the ETVI will allow for the improved study of urban climate mitigation strategies and the possible impact these strategies could have relative to community energy-transport vulnerability. We expect that when we evaluate decarbonizing urban strategies (e.g., alternative fuels and additional fuel taxes) in conjunction with spatially defined energy-transport vulnerable areas, certain strategies will be either more or less impactful on these already disadvantaged groups. In order to achieve low-carbon urban centers, we must understand the energy-transport poverty that shapes our societies and how decarbonizing policies could exacerbate or diminish these vulnerabilities attributing to the success or shortfall of the strategy.

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