Beyond compact development: Identifying housing locations that minimize travel with double machine learning

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Introduction

With climate change and rapid urban migration, cities face the question of where to locate new residents to minimize travel and associated CO_2 emissions. While the IPCC suggests general planning concepts such as compact or transit-oriented development, a place-specific understanding of how this translates into the local context is lacking. This study presents a novel approach to assess the induced transport CO_2 emissions for different urban planning strategies and to identify the city-specific, optimal locations for low-carbon residential development

Research question

Where should new housing development be located to minimize travel and associated CO_2 emissions?

Methods

We use double machine learning to estimate the effect of the built environment on travel-related CO_2 emissions for each neighborhood from harmonized travel surveys while controlling for the non-linear effect of residential self-selection.

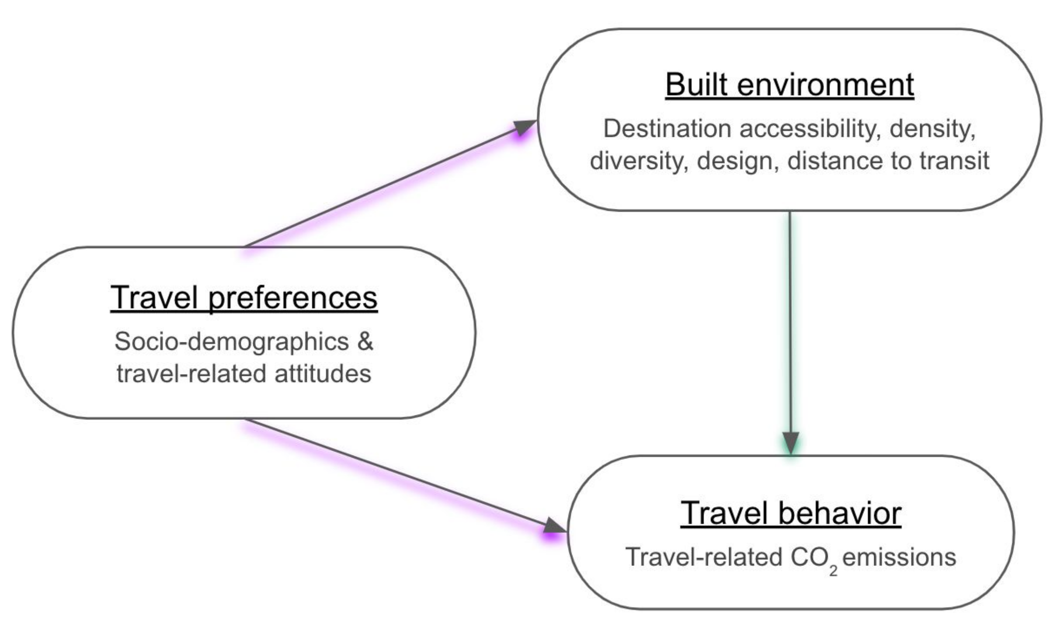

Figure 1. Directed acyclic graph (DAG) with direct (green) and confounding effect (pink).

Data & preprocessing
- Case study Berlin: Travel diaries from SrV mobility survey (32k participants)
- Calculate emissions based on travel distance, mode, and emission factors
- Average household travel-related emissions per residential zip code

Feature engineering
- Describe built environment along "5Ds": destination accessibility, density, diversity, design, and distance to transit

Causal inference
- Estimate treatment effect of built environment from observation data
- Confounders: Account for residential self-selection (RSS) using information on socio-demographics and ownership of transport means
- Treatment level: Difference to average built environment
- Model selection:
  - XGBoost for nuisance models to account for non-linear RSS
  - CausalForest for final model to capture heterogeneous effects

Use case 1: Evaluating currently planned housing projects in Berlin, Germany

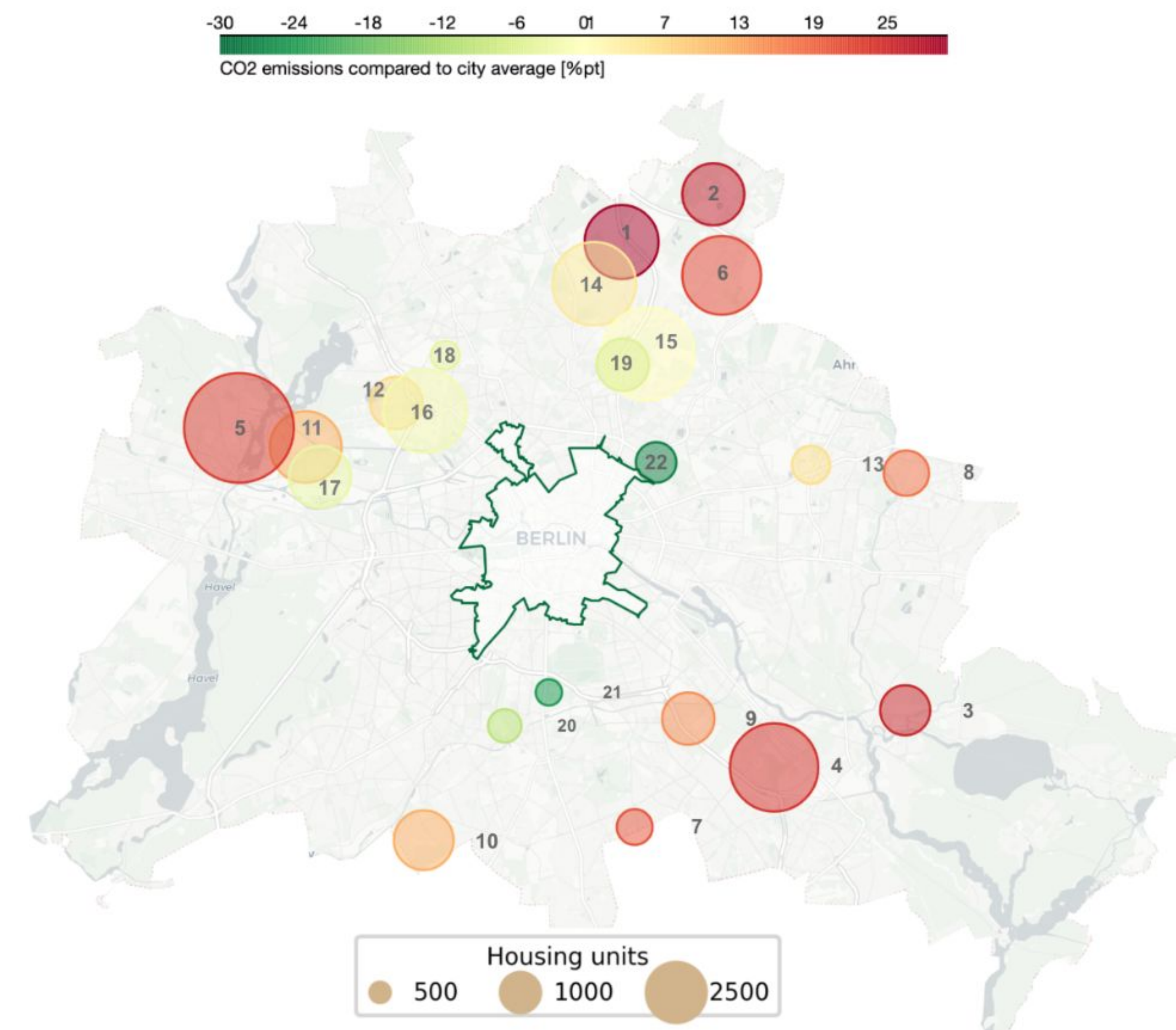

Figure 2. Planned settlements (circles) colored by expected travel-related CO_2 emissions and sized by housing units. The green border highlights neighborhoods with the largest emission reductions.

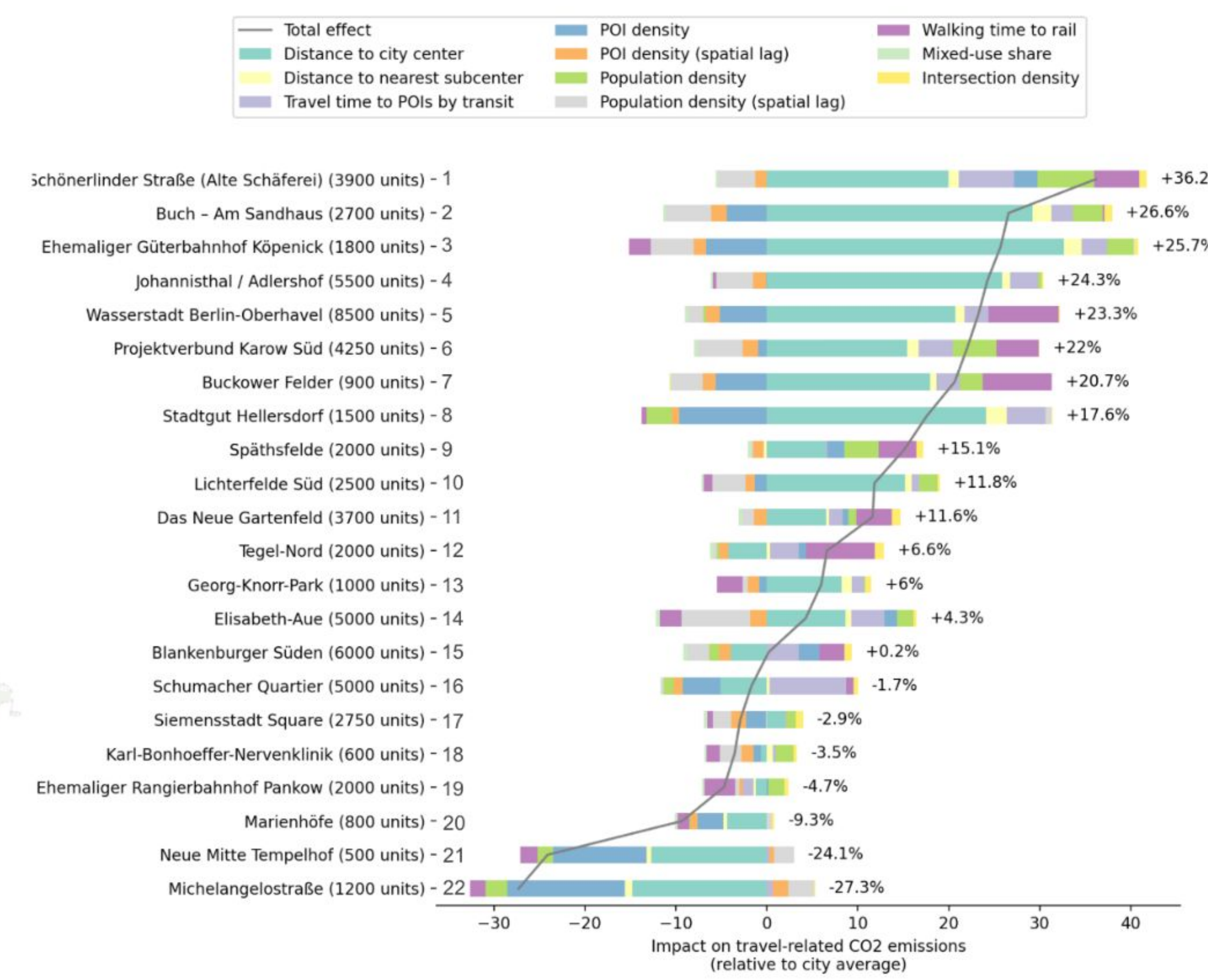

Figure 3. Decomposition of the built environment effect for each planned settlement. The gray line indicates the total effect relative to the city average travel-related CO_2 emissions.

Use case 2: Predictive modelling of changes in the built environment

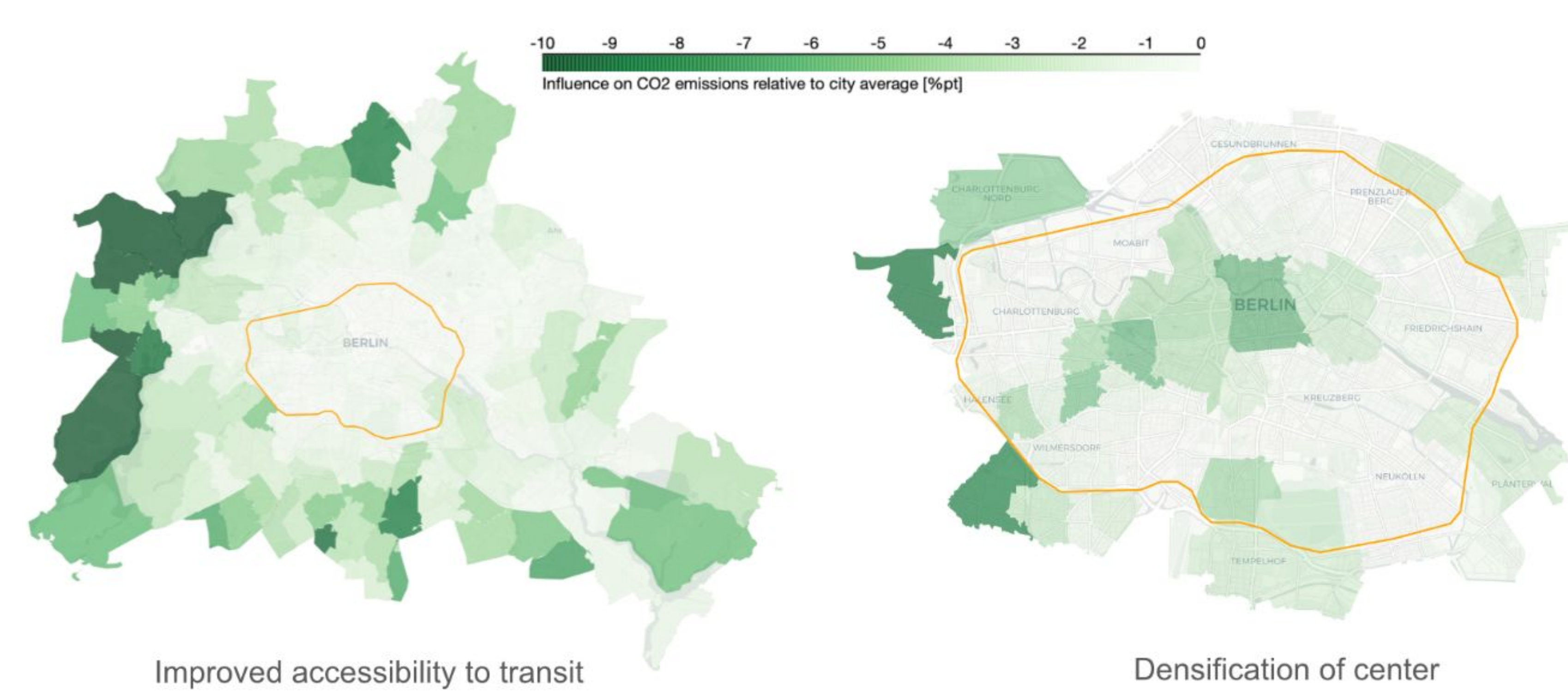

Figure 3. Exemplary demonstration of how the method can be used to prospectively model the effect of urban planning scenarios on travel-related CO_2 emissions.
- Left: Improving the accessibility of public transportation everywhere in Berlin to a maximum walking time of 5 minutes to the nearest rail station.
- Right: Densification of neighborhoods within or in close proximity to the "Ringbahn", an urban rail line that circles central Berlin (marked in orange)

Poster summarizes ongoing work based on:
Nachtigall, Florian, et al. "Built environment and travel: Tackling non-linear residential self-selection with double machine learning." Transportation Research Part D: Transport and Environment 140 (2025): 104593.

Results

- Built environment explains 72% of the variability in neighborhood-level CO_2 emissions in Berlin
- 15 of 22 planned housing projects in Berlin are expected to increase citywide per capita CO_2 emissions by 11.9% on average, mainly due to their large distance from the city center and low population density
- Compact development in the 20 lowest-emission neighborhoods could reduce future residents' CO_2 emissions by 42.9% compared to planned developments
- Improving transit access and densifying central neighborhoods could each reduce CO_2 emissions locally by up to 10%

Discussion & conclusion

DML can advance evidence-based low-carbon urban planning
- Spatial explicit estimates of representative travel-related CO_2 emissions facilitate residential planning

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