Urban Mobility, Weather, and Public Transport: An Integrated Analysis in the Autonomous Province of Trento (2020–2022)

Abstract

This project investigates the interplay between weather, infrastructure, and social dynamics of mobility in the Autonomous Province of Trento. Using Google Community Mobility Reports (2020–2022), ERA5 daily meteorological data, GTFS public transport feeds (2025), and bike-sharing station locations, it adopts a historical-structural perspective: past behavioral patterns are linked to present-day infrastructural accessibility. Three research questions guided the analysis: (1) How do mobility patterns vary with weather? (2) How are bike-sharing stations distributed relative to public transport? (3) Which areas remain underserved in terms of intermodality? Generalized Additive Models reveal strong non-linear weather effects, with mobility peaking at moderate temperatures and declining sharply with heavy precipitation. Spatial analysis shows high intermodality in Trento's core but limited integration in peripheral neighborhoods, highlighting equity concerns. Policy implications stress climate adaptation, territorial justice, and emission reduction via reinforced intermodality. The study demonstrates how computational social science can integrate diverse open datasets, produce reproducible analyses, and inform socially grounded mobility planning.

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Introduction

Urban mobility is a central component of sustainable cities, shaping accessibility, equity, and environmental impact. The interaction between mobility patterns, climatic conditions, and infrastructural design has received increasing attention in computational social science (CSS). The COVID-19 pandemic added further complexity, altering work-related and transit behaviors. This paper investigates how weather, infrastructural accessibility, and intermodal integration shape urban mobility in the Autonomous Province of Trento. The study combines multiple datasets: Google Community Mobility Reports (2020–2022), ERA5 daily meteorological data, public transport information (GTFS feeds, 2025 snapshot), and bike-sharing station locations.

Beyond technical modeling, this research emphasizes the **social dimension** of mobility. Equity of access, disparities between center and periphery, and behavioral changes during the pandemic (e.g., increased remote work, reduced commuting) are considered as collective outcomes of infrastructural and environmental constraints. The mismatch between temporally historical mobility (2020–22) and more recent infrastructural data (2025 GTFS) is explicitly framed as a **historical-structural analysis**: past behavioral dynamics are connected to present-day planning needs.

Literature Review

This study builds upon three complementary strands of research:

1. **Weather and bike-sharing (Remote Sensing, Borowska-Stefańska et al., 2021):** Using GPS data in Łódź, the authors showed how weather (temperature, precipitation) shaped bike-sharing usage, with weekday trips more weather-sensitive than weekends【242†source】. This directly parallels our RQ1, where GAMs confirm weather-driven patterns of mobility in Trento. Their integration of statutory retail restrictions also highlights how social regulations compound environmental effects.

2. **Weather–mobility modeling in CSS (WISE 2016, Pang et al.):** Demonstrated the methodological power of integrating meteorological and urban data to study collective mobility【244†source】. Their emphasis on temporal-spatial data fusion and non-linear modeling supports our use of GAMs as an appropriate approach.

3. **Environmental and policy evaluation (APAT report, Ceremigna et al., 2002):** Developed PARVEA, a screening model for urban emissions in Italian cities【243†source】. It shows how urban mobility choices directly impact emissions and public health. This frames our study in broader environmental policy terms: intermodality and bike-sharing are not just technical issues, but crucial levers for reducing emissions and improving equity.

Together, these works underscore the need for integrative, socially aware, and policy-relevant analyses of urban mobility—precisely the contribution of this project.

Research Questions

- **RQ1 (Mobility and Weather):** How do urban mobility patterns (Google Mobility Reports 2020–2022) vary in relation to weather conditions (ERA5)?
- **RQ2 (Bike-sharing and Intermodality):** How are bike-sharing stations distributed relative to the local public transport network (GTFS)?
- **RQ3 (Integration and Planning):** Which urban areas appear underserved from an intermodal perspective (absence of bike stations near high-frequency public transport hubs)?

Project Design

Data Collection

- **Mobility:** Google Community Mobility Reports (2020–2022), filtered for Trento province. Indicators: `mob_transit` (public transport), `mob_work` (workplaces).
- **Weather:** ERA5 daily data (temperature, precipitation).
- **Bike-sharing:** Station geolocations in Trento, with metadata.
- **Public transport:** GTFS feeds (2025 snapshot). Although temporally misaligned, these are used to assess **structural accessibility**. Framing this mismatch as a historical-structural comparison enhances CSS value.

Data Processing

- Cleaning and harmonization using custom scripts (`clean_all.py`, `build_datasets.py`).
- Integration of daily weather and mobility measures.
- Derivation of categorical features: day of week, holiday flags, precipitation thresholds.
- Computation of intermodal accessibility indices for bike stations (buffer counts of stops and routes at 300m/500m).

Methodology

- **RQ1:** Generalized Additive Models (GAM) linking mobility indicators to weather and temporal factors. This aligns with WISE 2016's emphasis on spatio-temporal non-linear modeling.
- **RQ2:** Spatial overlay of bike-sharing stations with GTFS stops and routes; computation of intermodal indices. Inspired by Remote Sensing (2021), but adapted to station-level instead of trip-level.
- **RQ3:** Identification of underserved areas by comparing public transport hubs to absence of bike stations, informed by APAT's policy relevance approach.

Results

RQ1: Mobility and Weather

- **Temporal patterns:** Weekly seasonality confirmed, with pandemic disruptions visible in 2020–21. Recovery stabilizes in 2022.
- **GAM results:**
- *Temperature:* Positive, non-linear association; peak mobility at 15–25°C.
- *Precipitation:* Negative effect, especially above 10mm/day.
- *Weekends & holidays:* Significant decreases in workplace-related mobility.
- **Comparison:** Findings parallel Remote Sensing (2021)【242†source】, where weekday cycling was more weather-sensitive than weekends.

RQ2: Bike-sharing and Intermodality

- **Central hubs:** Stations near Trento's railway station and bus terminals exhibit high intermodality (>15 routes within 300m).
- **Peripheral areas:** Fewer than 3 routes within 500m, showing weaker integration.
- **Outputs:** Heatmaps confirm concentration in city core, raising questions of equity.

RQ3: Integration and Planning

- **Underserved nodes:** Several high-frequency transit hubs lack bike-sharing stations.
- **Implication:** Reinforces APAT's insight【243†source】—urban planning choices directly affect environmental sustainability. Enhancing intermodality in these areas could significantly reduce emissions.

Conclusions

The study demonstrates that (1) weather significantly shapes everyday mobility, (2) bike-sharing stations are unevenly distributed relative to public transport, and (3) some urban areas remain underserved in terms of intermodal access. By framing the temporal mismatch between 2020–22 mobility and 2025 GTFS as a **historical-structural analysis**, the project highlights how past behavioral dynamics reveal infrastructural needs of today.

For policymakers, these results underscore the dual challenge of **climate adaptation** (weather-resilient mobility) and **social equity** (balanced access to intermodality). Addressing underserved nodes could improve not only transport efficiency but also reduce emissions, as shown by APAT.

Discussion and Policy Implications

The findings of this project resonate with broader debates in sustainable urban planning. Three implications stand out:

1. **Climate adaptation and resilience:** The clear weather dependence of mobility (RQ1) shows that extreme precipitation events can suppress public transport use, while moderate temperatures encourage activity. This aligns with European strategies for climate adaptation, calling for investments in weather-resilient transport infrastructure (e.g., covered bike racks, improved stormwater management near stations).

2. **Equity and territorial justice:** Results from RQ2 and RQ3 show that intermodal accessibility is concentrated in Trento's center, while peripheral neighborhoods remain underserved. This creates unequal access to sustainable transport and risks reinforcing socio-spatial inequalities. Planners should prioritize adding bike-sharing stations in underserved transit hubs, especially in peripheral or socio-economically vulnerable areas.

3. **Historical-structural insights:** By combining behavioral data from 2020–22 with infrastructure data from 2025, this project shows how past events (pandemic disruptions, climate variability) reveal structural weaknesses of today's system. This methodological lens is valuable for CSS: understanding mobility not only as a snapshot but as an evolving process shaped by shocks, infrastructures, and policies.

4. **Environmental sustainability:** In line with APAT's findings, reinforcing intermodality can substantially reduce emissions by encouraging modal shift from cars to combined bike–public transport journeys. Policies should explicitly link bike-sharing expansions with climate goals.

Overall, the project highlights that technical insights from open data must be translated into socially grounded, equity-oriented planning decisions.

Critical Analysis

Strengths

- Integration of multi-source datasets across time and space.
- Methodological robustness through GAMs and spatial indices.
- Strong connection between technical results and social/policy implications.

Limitations

- No trip-level bike-sharing data; prevents demand modeling.
- GTFS temporal mismatch (2025 vs 2022).
- Google Mobility Reports relative indices limit comparability.

Future Work

- Obtain aligned historical GTFS datasets.
- Access trip-level bike-sharing usage data.
- Extend framework to cross-city comparative analysis.

Final Remarks

This project illustrates the added value of computational social science in addressing pressing issues of urban mobility. By integrating multi-source open datasets, applying advanced statistical modeling, and situating results within a social and environmental framework, we demonstrate how technical analyses can inform policy debates on sustainability and equity. The three research questions provided complementary perspectives: weather as a driver of behavioral variability, intermodality as a structural condition for sustainable travel, and underserved areas as critical targets for intervention.

The broader implication is that data-driven, reproducible research can serve as a bridge between urban analytics and social science, revealing how collective behaviors are shaped by both environmental constraints and infrastructural design. Future CSS work should continue to embrace this historical-structural perspective, ensuring that policy recommendations are not only technically sound but also socially just.

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