Local Resources for Urban Climate Research and Education at ASU

Navigating Deep Uncertainty: Robust Transportation Decisions Under Extreme Heat

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Overview

In transportation systems in heat-stressed cities, greater reliance on automobiles as a cooling resource reflects the system's capacity to adapt, but it is contingent on increased CO2 emissions, which hinder climate mitigation goals.

The way these trade-offs evolve over time depends on several deep uncertainties, such as extreme weather, the introduction of disruptive technologies, social dynamics, and economic transitions, among others [1].

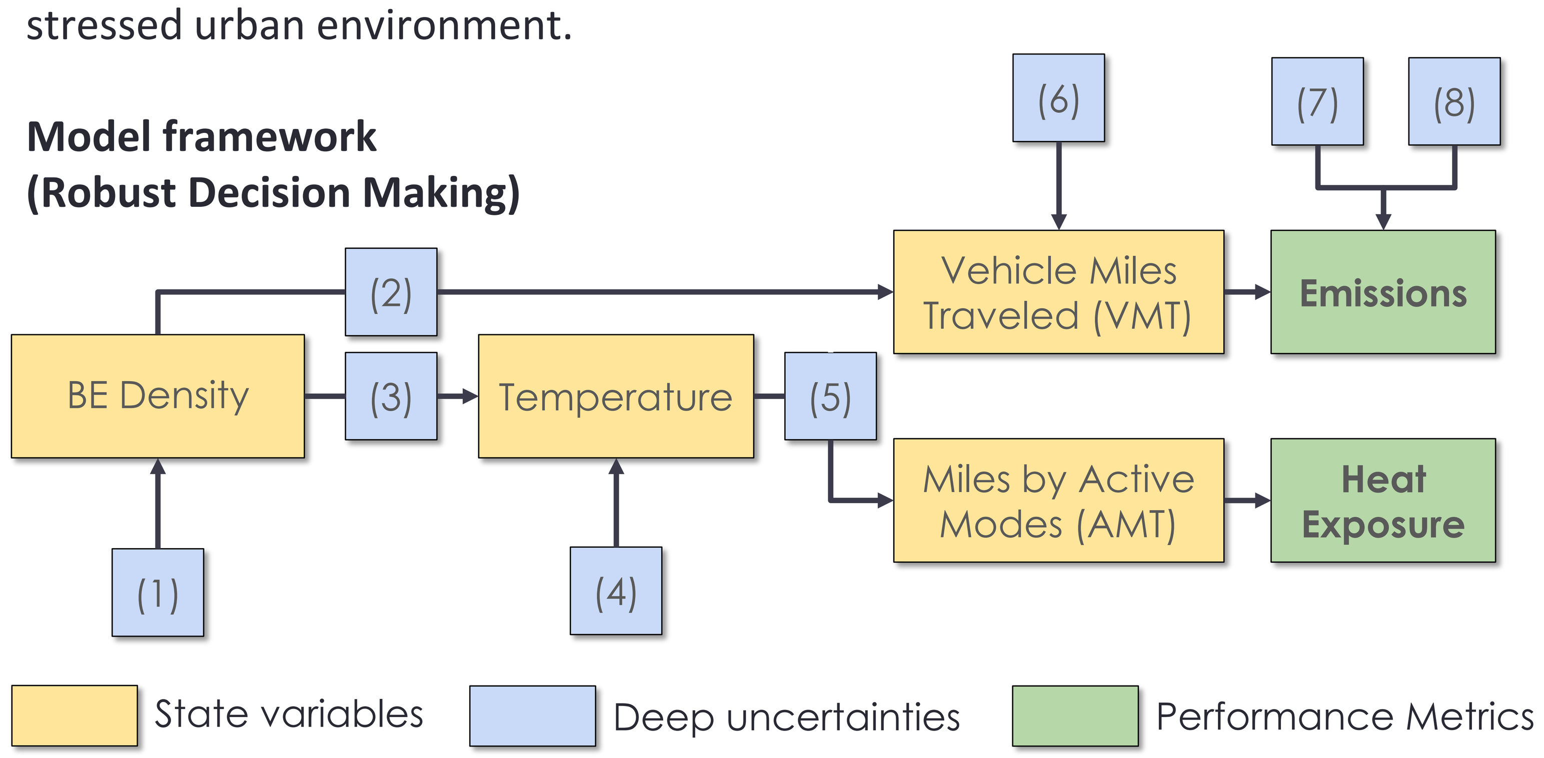
Current infrastructure planning methods are unable to capture such dynamic, complex interactions [2][3], generally providing little insight into the conditions that shape desirable and undesirable pathways toward equitable, low-carbon, and adaptive urban transportation futures [4].

To fill this gap, this work explores ways to manage transportation-related mitigation-adaptation trade-offs in cities impacted by extreme heat under deeply uncertain future conditions.

Approach

We develop a model based on a system of equations that captures the time-varying behavior of mode share (active mobility vs. car use) as responses to changes in built environment (BE) density and temperature. The main outcomes are estimations of future emissions and heat exposure for a generic heat-stressed urban environment.

Model framework
(Robust Decision Making)



(1) BE Density Change; **(2)** BE Density-induced Travel Behavior; **(3)** BE Density-induced Temperature Change; **(4)** Climate-driven Temperature Increase; **(5)** Temperature-induced Travel Behavior; **(6)** Population Growth Rate; **(7)** Electrification Growth Rate; **(8)** Emission Factors.

$$\boldsymbol{Emissions} = P\,(1 - ER)\,VMT_{per\ agent}\,EF$$

$$\boldsymbol{Heat\ Exposure} = P\,AMT_{per\ agent}\,T$$

$$\boldsymbol{VMT_{per\ agent}} = f(\rho, \Delta T) = \alpha\,\rho^{\lambda_1}\,\Delta T^{\lambda_2}$$

$$\boldsymbol{AMT_{per\ agent}} = f(\rho, \Delta T) = \frac{TMT_{per\ agent} - VMT_{per\ agent}}{cf}$$

Where:
P: Population; ER: Electrification Rate
EF: Emission Factors
T: Temperature
ρ: BE Density; α: Scaling Factor
VMT: Vehicle Miles Traveled
AMT: Active Miles Traveled
TMT: Total Miles Traveled
cf: Conversion Factor (VMT/AMT)
λ_1: $Density-induced\ travel\ behavior$
λ_2: $Temperature-induced\ travel\ behavior$

Navigating Uncertainty

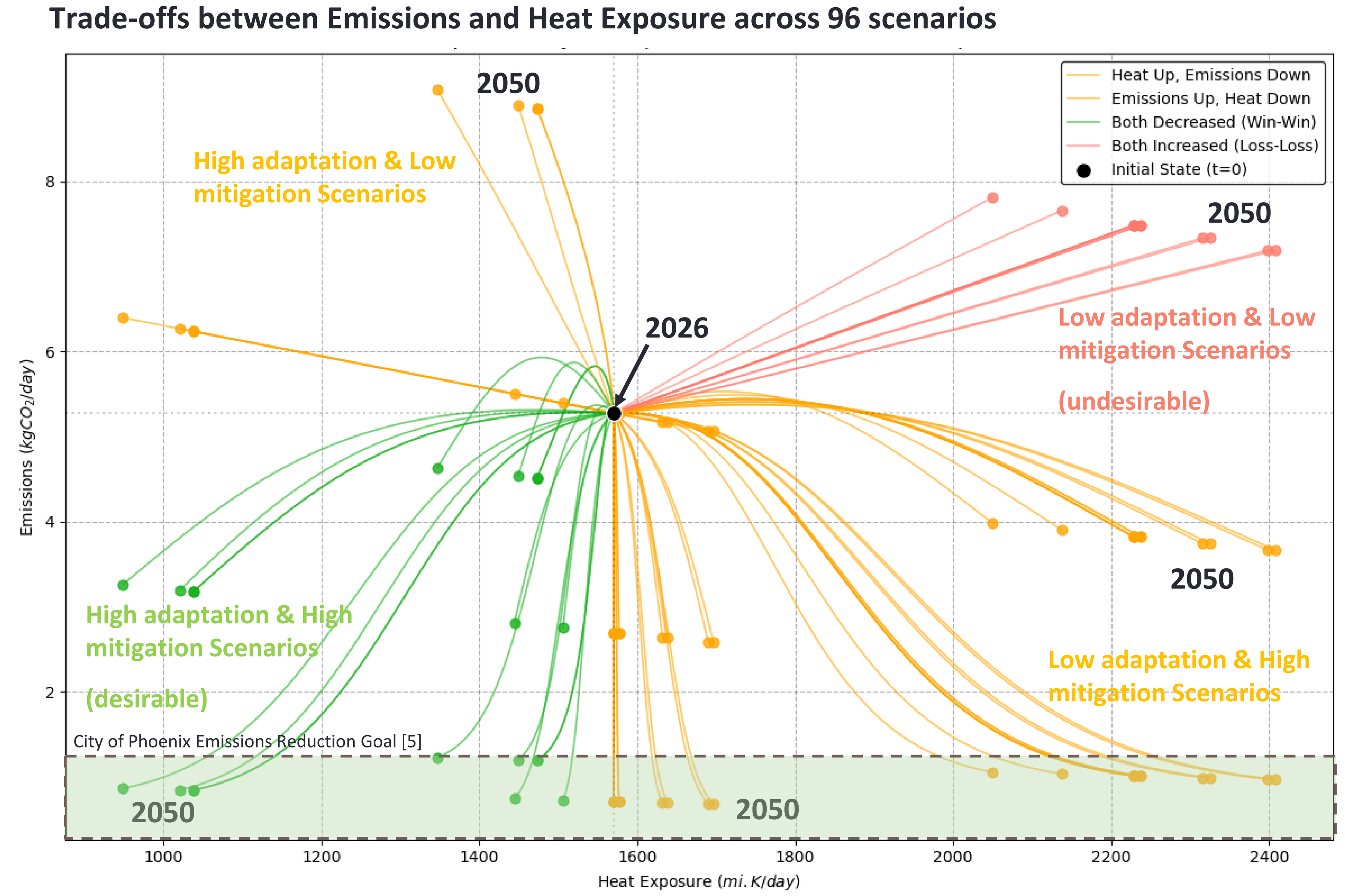
We assess 96 plausible future scenarios, i.e., different combinations of deep uncertainties, across the following ranges:

Climate-driven Temperature increase (K/year)	Population Growth Rate ($year^{-1}$)	BE Density Change ($population/mi^2.year$)	Density-induced Travel Behavior (unitless)
0 | 0.05	0 | 0.014	0 | 20	-0.1 | -0.05
Temperature-induced Travel Behavior (unitless)	**Electrification Growth Rate ($year^{-1}$)**	**Emissions Factor (kg CO_2/mi)**	**Time frame (years)**
0 | 0.50	0 | 0.125 | 0.25	0.37	25

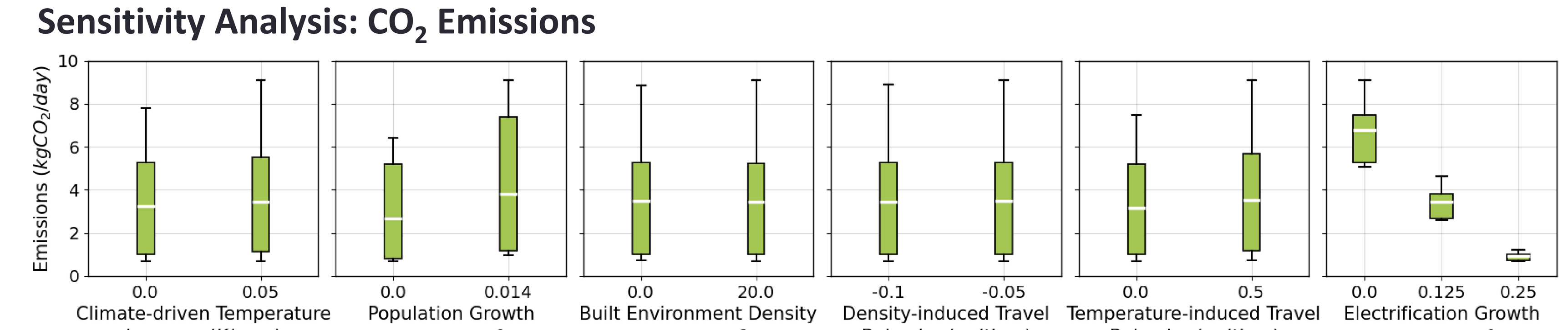
Initial conditions (similar across all 96 scenarios):

VMT per agent (mi/day)	AMT per agent (mi/day)	Electrification Rate (%)	Population (agents)	BE Density ($population/mi^2$)
15	5	5	1	1,000

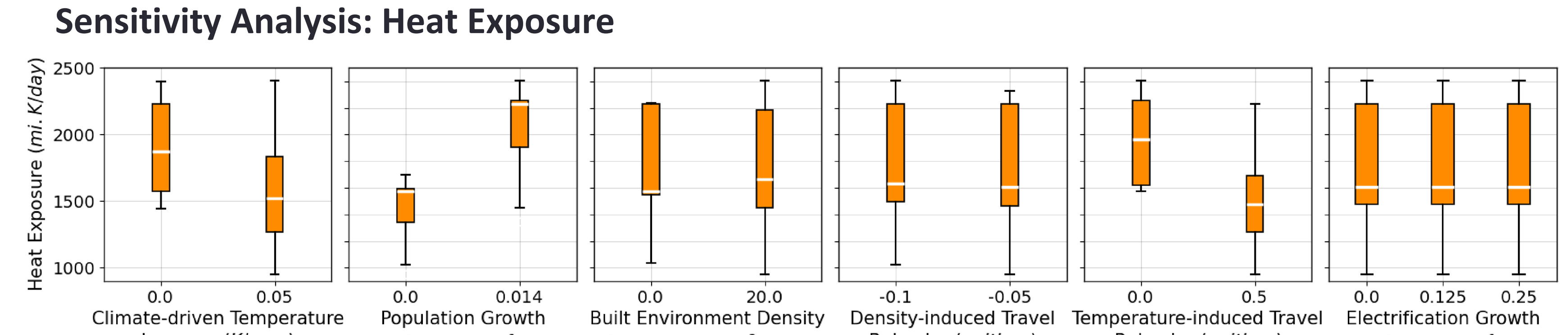
Trade-offs between Emissions and Heat Exposure across 96 scenarios



Sensitivity Analysis: CO_2 Emissions



Sensitivity Analysis: Heat Exposure



Discussion

Different conditions of deep uncertainties can lead a transportation system in heat-stressed cities towards very distinct future pathways (desirable or undesirable).

Future pathways can present non-linear behavior. In some desirable trajectories, emissions increase before going down.

Climate-driven temperature increases, population growth, travel behavior, and growth rates in automobile electrification represent key deep uncertainties that influence how CO2 emissions evolve.

Most simulated deep uncertainties affect heat exposure, but temperature-induced travel behavior (agents' sensitivity to temperature increases) and population growth rate are the most critical ones.

High electrification growth rates to meet increased driving demands must be accompanied by the provision of cooling resources for vulnerable populations to achieve desirable adaptive pathways (High mitigation and high adaptation).

Conclusion

Increasing uncertainty about the social, environmental, and technological pressures that will impact infrastructure systems requires the application of novel tools to navigate the planning trade-offs that emerge from such non-stationary conditions.

We are currently stress-testing the model across a wider range of future scenarios to identify the specific conditions that lead transportation systems impacted by extreme heat towards different future pathways.

Findings provide insights into robust strategies that cities like Phoenix could implement to achieve multiple planning goals (e.g., reducing CO2 emissions, reducing travel, improving air quality, and helping communities cope with extreme heat).

References

[1] Lempert, R., Popper, S., Hernandez, C. (2021). Transportation Planning for Uncertain Times: A Practical Guide to Decision Making Under Deep Uncertainty for MPOs. U.S. Department of Transportation: Federal Highway Administration. https://rosap.ntl.bts.gov/view/dot/64646

[2] Lempert, R., Syme, J., Mazur, G., Knopman, D., Ballard-Rosa, G., Lizon, K., & Edochie, I. (2020). Meeting Climate, Mobility, and Equity Goals in Transportation Planning Under Wide-Ranging Scenarios: A Demonstration of Robust Decision Making. Journal of the American Planning Association, 86(3), 311–323. https://doi.org/10.1080/01944363.2020.1727766

[3] Markolf, S. A., Hoehne, C., Fraser, A., Chester, M. v., & Underwood, B. S. (2019). Transportation resilience to climate change and extreme weather events – Beyond risk and robustness. Transport Policy, 74, 174–186. https://doi.org/10.1016/J.TRANPOL.2018.11.003

[4] McPhearson, T., M. Raymond, C., Gulsrud, N., Albert, C., Coles, N., Fagerholm, N., Nagatsu, M., Olafsson, A. S., Soininen, N., & Vierikko, K. (2021). Radical changes are needed for transformations to a good Anthropocene. In npj Urban Sustainability (Vol. 1, Issue 1). Springer Nature. https://doi.org/10.1038/s42949-021-00017-x

[5] City of Phoenix. (2025). 2050 transportation goals. Available at: https://www.phoenix.gov/administration/departments/sustainability/2050-sustainability-goals/2050-transportation-goals.html

Acknowledgments

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