Urban Climate Futures Lab (UCFL): Advancing Inter- and Transdisciplinary Research for Sustainable Urban Development

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1 ABSTRACT

The Urban Climate Future Lab (UCFL) is a multidisciplinary research initiative designed to investigate and address the complex interplay between urban development, climate change impact as well as mitigation and adaption, with a particular focus on Lower Saxony and its transferability to wider global contexts. It is funded by zukunft.niedersachsen, a funding program of the Lower Saxony Ministry of Science and Culture and the Volkswagen Foundation. UCFL's unique value lies in bridging the gap between fundamental and transformative research, aligning academic excellence with real-world implementation and stakeholder engagement, reflected within a global perspective.

Keywords: Urban development, climate change adaptation, climate change mitigation, interdisciplinary research, sustainability

2 INTRODUCTION

The Urban Climate Future Lab (UCFL) targets some of the most pressing issues of our time: climate change mitigation and adaptation. Because climate change will increasingly affect urban spaces, the project focuses on urbanization, integrating its different facets: from livability, sustainable mobility, urban production, green infrastructure, resource and energy consumption, climate change risk perception, needs and behaviors of citizens, and efficient and just governance. With UCFL we want to create fundamental knowledge and progressive methods to address holistic, multi-scalar urban solutions, leveraging cross-sector expertise across architecture and planning, social sciences, engineering, and climate science. It seeks to develop and refine new models and tools for assessing and transforming urban areas in light of climate change. This approach is not limited to theoretical exploration; it also addresses practical application, with a focus on both holistic mitigation and adaptation strategies in urban settings. The UCFL project set to span six years is structured into two distinct but interconnected phases: In phase (I), we focus on system knowledge and method

development: How do different settlement types in the Lower Saxony urban and rural systems contribute to climate change, and how are they affected by it? In phase (II), we will focus on transformation knowledge: How can the Lower Saxony urban system, and its constituting elements be transformed to reduce climate impacts and increase its overall resilience and sustainability? Over and beyond the project the aim of UCFL is to evolve into a competence center for research and practice in questions of sustainable urban adaptation to climate change and other tackling emerging aspects of future urban and regional development.

The UCFL's innovative approach is distinguished by its comprehensive and interdisciplinary nature. It brings together a team from several research institutions, including Technische Universität Braunschweig, Leibniz University Hannover, Leuphana University Lüneburg, the ARL – Academy for territorial development in the Leibniz Association, and the Climate Service Center Germany (GERICS), an institution of Helmholtz-Zentrum Hereon. This expertise is supplemented by a distinguished international and interdisciplinary advisory board, ensuring the project's critical reflection from a global perspective. To increase the impact, UCFL strategically partners with researchers, civil society, planning entities, industry and NGOs to address the various facets of urban and climatic dynamics in a holistic way. Methodologies adopted are inter- and transdisciplinary, merging insights and techniques from a large range of disciplines.

UCFL sets out to establish a joint model-based and knowledge-driven approach to continuously analyze, evaluate and refine urban development strategies, thereby creating a dynamic framework for urban adaptation to climate change. Another key objective is to influence policy and practice by providing politically and socially negotiable scenarios, actionable recommendations and guidelines for policymakers and industry stakeholders. The project is structured around several key sub projects (SPs). URB explores settlement patterns and their interlinkages and development scenarios along the urban-rural gradient. MOB focuses on the integrated planning of mobility, analyzing how urban structures influence travel behavior and transport-related climate impact. SYM investigates urban factories and industrial symbiosis. RES addresses urban resource and energy management. OPEN focuses on the holistic accounting and climate-friendly transformation of different types of urban open spaces. CLIM involves climate change impact assessment. CIT captures citizens' narratives of climate change risks. GOV addresses integrative governance for resilient and climate-just spatial transformations. KNOW integrates all SPs by facilitating data exchange, modeling, and scenario building. COLAB manages project organization, infrastructure, and communication, coordinating activities like workshops, science communication, and research proposals while developing a strategic road map for UCFL, aligning stakeholder efforts, securing funding, and planning for its long-term regional and international impact.

This paper outlines UCFL's conceptual framework, methodologies, and ongoing work-streams, emphasizing its role as a model for synergistic research ecosystems. This contribution aims to introduce the project to a wide audience of academics and practitioners in the field fostering international collaboration and knowledge exchange with the UCFL. By addressing knowledge gaps and promoting innovation in sustainable urban and regional planning with specific focus on climate change mitigation and adaptation, UCFL sets the foundation for shaping sustainable urban regions worldwide.

3 THE PROBLEM

The effects of climate change on urban areas are multifaceted and far-reaching (IPCC, 2022). Historically, there has been a correlation between urbanization, industrialization, mobility, population growth, globalization and the rise of carbon emissions (van den Berg., 1987). While urbanization can be associated with many positive effects for societies and individuals, like the increase of living standards, negative effects concern e.g., the unbalanced concentration of resource consumption in urban areas, the associated loss of biodiversity and space (Zucaro, Maselli & Ulgiati., 2022; Wilting et al., 2017; Kim et al., 2021), increased climate change risks, such as heat islands, heavy rain events, floods, droughts, storm surges etc. (IPCC, 2022; Bertrand-Krajewski, 2021), and a lack of resilience through the urban form itself (ZSK, 2022). Urban development can lead to landscape fragmentation, urban sprawl, changes in forest resources as well as land use, with negative consequences for biodiversity (Ünal Steg & Gorsirg, 2018). The expansion of urban areas can also exacerbate environmental problems such as air pollution, heat islands, and the loss of natural habitats (Richards & VanWey, 2015). While cities and urban areas are home to a larger proportion of the population and therefore proportionally more resources are consumed, they are also most threatened by climate change (IPCC, 2022; Kim et al., 2021; Ye & Niyogi, 2022), but may embody high potential for

positive impact (Liu et al., 2023; Kraas et al., 2016). Additionally, the construction industry, the expansion of urban infrastructure, and the increasing energy demand in cities lead to high greenhouse gas emissions (Elmqvist et al., 2021; Seto et al., 2016).

However, cities are also hubs for innovation and adaptation to climate change. Green and blue infrastructure approaches, such as urban parks, hybrid spaces, decentralized storm water management, or vertical green, have been shown to mitigate the impacts of extreme weather events like floods and heat (Tauhid & Zawani, 2018). Furthermore, mitigation strategies that focus on reducing energy demand and land-based resources can reduce trade-offs with sustainable development (IPCC, 2022).

According to the IPCC (2022), urban areas are expected to experience increased temperatures and changes in precipitation patterns due to climate change. Lower Saxony's settlement units will also be heavily affected by this, which may lead to more frequent heatwaves, droughts, and heavy rainfall events, which can have devastating impacts on urban infrastructure and human health. Overall, understanding the complex relationships between urbanization, climate change, and environmental degradation is crucial for developing effective mitigation and adaptation strategies (IPCC, 2022).

Understanding urbanization's role in environmental degradation requires a nuanced approach. Different urban morphologies – shaped by their economic structures, infrastructure, and governance – leave distinct environmental footprints. A large city reliant on coal power plants has a vastly different impact compared to a small agricultural town, where pesticide runoff affects surrounding water bodies. While both contribute to environmental degradation, they do so through different modes of environmental degradation and at different scales, making direct comparisons difficult. Furthermore, Phase I focuses on assessing how climate change will affect different settlements, while Phase II identifies the interventions needed to transform them into more resilient and sustainable spaces, which may vary significantly in scope and strategy.

4 THE APPROACH

The project focuses on analyzing the diverse environmental impacts of settlement units across Lower Saxony – from urban to rural forms – and their inter-linkages along the urban-rural gradient, exploring plausible social-ecological transition scenarios, and assessing who is likely to be disproportionately affected by these transitions. At the same time, the project investigates how different settlement types across the federal state will experience the effects of climate change.

Crucially, climate change impacts cannot be understood solely through the quantification of changing climate variables at a coarse spatial scale – although this remains a fundamental part of the project. Instead, UCFL incorporates additional parameters such as:

- Existing green infrastructure within settlements, which influences local climate regulation.
- Urban morphology, which affects vulnerability to extreme weather events.
- Socio-economic structures, which shape communities' ability to adapt and respond to climate risks.

By combining methodologies from urban planning, sociology, global and regional climate models, socio-economic analysis, and environmental modeling, UCFL seeks to provide a holistic understanding of the interrelationships between urbanization and climate change. The insights generated will support evidence-based policy making, helping cities and regions navigate a transition toward more sustainable and resilient futures.

The Urban Climate Future Lab (UCFL) aims to set up a research- and cooperation-platform systematizing this complex challenge by integrating multiple disciplines to develop interdisciplinary approaches that examine two key aspects: (1) The environmental impact of different urban settlements and their urbanization patterns, and (2) the ways in which these different settlements are expected to be affected by a changing climate.

To address the challenges of climate change in urban areas, UCFL proposes a multifaceted approach that blends knowledge creation, technological innovation, policy frameworks, community engagement and seeks to understand the research objects as coupled human-environment systems. The solutions we recommend aim to reduce urban carbon footprints, enhance resilience, and promote sustainable development and livable environments through coordinated efforts across various sectors. One of the key areas for intervention is land

uptake, the functional layout of settlement types and their interconnections within the urban system to create or discourage synergies between land use types and everyday life actions. This is related to all of the other facets of sustainable development. Transportation also plays a major role in urban carbon emissions. Transport oriented planning of settlements and the development of infrastructure that supports electric or hybrid vehicles, along with good public transportation options and cycling networks, can reduce dependence on fossil fuels. As more people adopt sustainable and more active travel behavior urban settlements can lower their transportation-related carbon footprint, contributing to cleaner air and a more sustainable urban mobility system and significantly reduce the sealing of land and consumption of space.

Another key topic is the industry sector. We approach this topic by looking at urban factories and urban in industrial symbiosis (UrIS), which refers to the communal sharing of physical and intangible resources among diverse urban entities, such as businesses and public institutions. By integrating circular economy practices, where materials are reused and recycled, urban systems can minimize their environmental footprint and create a more sustainable, closed-loop economy.

Another critical solution is urban greening, which involves expanding green spaces through tree planting, green roofs, rainwater retention and other forms of urban greening. These green spaces function as carbon sinks, improve air quality, and reduce the urban heat island effect, which can exacerbate the impacts of climate change. In addition to these environmental benefits, urban green-blue spaces enhance biodiversity and offer recreational areas for residents, improving the quality of life in urban settlements.

Building infrastructure and associated energy supply systems play a significant role in terms of emissions as energy efficient building design as well as decarbonization of operational energy demand for heating and electricity usage are key drivers for climate neutrality. Therefore, the significant share raise of renewable energy sources, such as solar, wind, and geothermal as well as district energy networks in urban settlements can substantially reduce greenhouse gas emissions. Retrofitting existing buildings to improve insulation and energy performance is another vital step in curbing overall energy consumption. This shift not only addresses climate change but also helps create a more energy-resilient urban landscape. Within UCFL, we aim to develop energy-efficient transition scenarios for the different settlement types across Lower Saxony.

The integration of data and digital technologies is another key solution. By simulating, for example resource consumption patterns like energy and water use, or other aspects or urban systems like transport networks, cities can better manage resources and identify inefficiencies. Contextualized urban data also enables better preparedness for extreme weather events, improving cities' ability to respond to climate impacts in real time. Advanced data driven methods support cross-scale and cross-domain planning and helps to optimize the allocation of resources, enhancing the resilience of cities to changing climatic conditions and understanding the impacts on a local scale.

Effective policy and governance are crucial in driving change. Policies that provide incentives for sustainable practices, such as sustainable territorial and land use planning, green building standards or low-carbon transportation options, help create a framework for climate action. At the same time, penalizing high-emission behaviors and rewarding low-carbon alternatives will steer urban settlements toward a more sustainable path. Data and digital technologies serve as key enablers, providing real-time insights, optimizing resource use, and enhancing decision-making for more effective policy implementation. Governments play a pivotal role in shaping the regulatory environment that encourages sustainable development while mitigating the risks of climate change.

Lastly, community engagement is vital for ensuring that these solutions are inclusive and effective. In the context of UCFL, a key focus is understanding how residents perceive climate change, their personal contribution to environmental impacts, and their sense of risk associated with climate change. By gathering insights on these aspects, we can better tailor interventions that resonate with local populations and encourage meaningful action. Educating and involving communities in sustainability efforts fosters a culture of climate action that extends beyond top-down policies. Grassroots movements complement governmental and technological strategies, creating a sense of ownership and accountability among residents. Local energy communities are another opportunity for communal residential involvement. When communities are actively engaged, they contribute to long-lasting change that reflects local needs and priorities.

5 THE TEAM

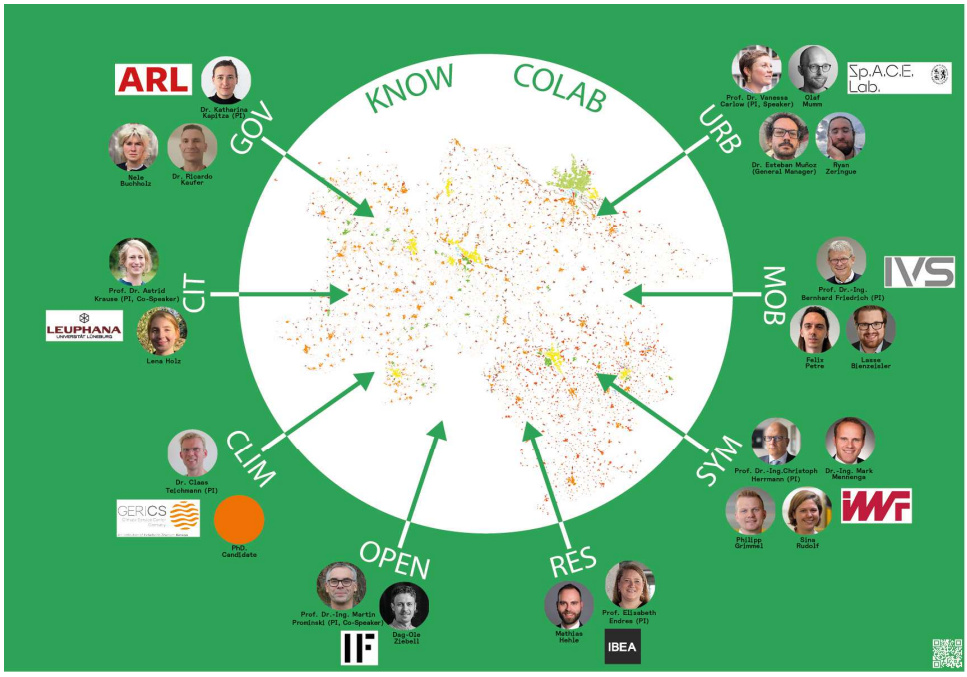

Fig. 1: Diagram showing the teams of the sub-projects. Source: Map in the background, settlement units of Lower Saxony (Initial TOPOI classification at cluster depth 75) based on the TOPOI method (Carlow et al., 2022)

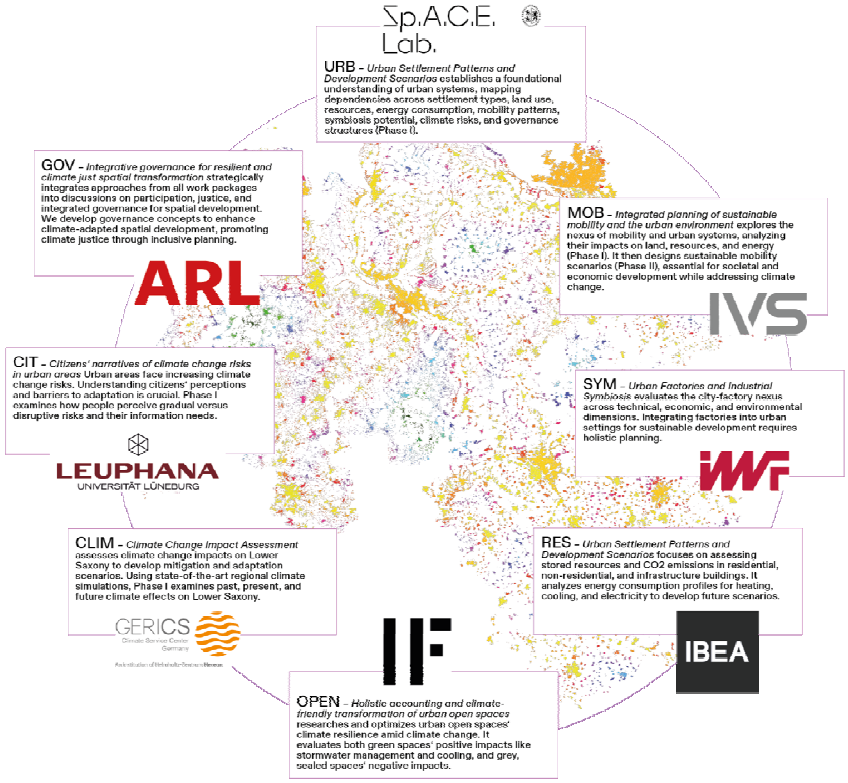

Fig. 2: Diagram showing the different sub-projects. Source: Map in the background, settlement units of Lower Saxony (PRTS – Proximity to Regional Train Station) based on the TOPOI method (Carlow et al., 2022)

UCFL brings together a diverse and highly experienced team of researchers with expertise from various fields, including urbanism, planning, sustainability, climate science, transportation, engineering as well as psychology and behavioral decision research, to develop integrated solutions for climate-resilient urban areas. The principal investigators represent renowned research institutions such as the ISU – Institute for Sustainable Urbanism at Technische Universität Braunschweig, the Institute of Sustainability Psychology (ISP) at Leuphana University Lüneburg, the Institute of Open Space Planning and Design (IF) at Leibniz

University Hannover, the Institute for Building Climatology and Energy of Architecture (IBEA), the Institute of Transportation and Urban Engineering the Institute of Machine Tools and Production Technology (all Technische Universität Braunschweig), the ARL – Academy for territorial development in the Leibniz Association, and the Climate Service Center Germany (GERICS) at the Helmholtz-Zentrum Hereon.

Each sub-project within the project focuses on different dimensions of urban climate challenges, from understanding urban settlement patterns and mobility to assessing climate change risks and governance strategies. Figures 1, and 2 showcase the collaborative spirit of the UCFL team, including a diagram of the working teams and one of the SPs. These visual elements highlight the close coordination and multidisciplinary approach that underpin the project's success.

Figure 2 provides an overview of the sub-project (SPs) that form the foundation of our research, each addressing a critical aspect of urban sustainability and climate adaptation. URB examines urban settlement patterns and development scenarios, mapping dependencies across land use, resources, energy, mobility, and governance structures. OPEN focuses on the role of urban open spaces in enhancing climate resilience, assessing both the benefits of green spaces and the challenges posed by gray infrastructure. SYM explores industrial symbiosis, evaluating the integration of factories into urban environments for sustainable development. CIT investigates citizen perceptions of climate risks, identifying barriers to adaptation and strategies to improve acceptance of sustainable urban transformations. MOB studies the interconnections between mobility and urban systems, designing sustainable mobility scenarios to address resource and energy consumption. CLIM assesses climate change impacts on Lower Saxony, using regional climate simulations to develop mitigation and adaptation strategies. RES analyzes energy consumption in buildings and infrastructure, modeling future scenarios for energy use and emissions reduction. Finally, GOV synthesizes insights from all SPs, developing integrative governance approaches that enhance participation, justice, and resilience in climate-adapted spatial planning. Together, these SPs provide a comprehensive framework for understanding and advancing sustainable urban transformation.

To further enhance the interdisciplinary nature of the project, two dedicated SPs have been established. The first, COLAB, focuses on fostering coordination and collaboration between the various research teams and investigators, ensuring that all SPs are aligned in their objectives and methodologies. The second, KNOW, is dedicated to the integration of data and knowledge across disciplines, enabling a seamless exchange of insights and promoting the synthesis of findings from different SPs. These efforts are key to ensuring that the project benefits from a truly holistic and interdisciplinary approach to urban climate challenges.

6 THE CHALLENGE AHEAD

The challenge ahead lies in navigating the complex and interconnected nature of urban systems and climate change. With urbanization continuing to intensify across the globe, understanding the environmental impacts of different urban settlements and their vulnerability to climate change is crucial. However, this task is far from straightforward, as urban settlements are diverse, with varying socio-economic fabrics, infrastructure, and resource management strategies. Developing effective, context-specific solutions requires not only technical expertise across a range of disciplines but also the ability to navigate differing local conditions, governance structures, and public attitudes. Integrating data from various sources, assessing the impact of climate change under different scenarios, and designing effective adaptation and mitigation strategies presents a multifaceted challenge that will require close collaboration and constant iteration.

7 EXPECTATIONS

The UCFL project has set ambitious goals for understanding and addressing the climate risks faced by urban settlements in Lower Saxony. By applying interdisciplinary approaches and advanced methodologies, we aim to gain new insights and develop tailored strategies that will allow urban areas to transition toward greater climate resilience and sustainability. Through the integration of diverse data sources, collaboration among research institutions, and active involvement of local stakeholders, we expect to create a comprehensive, actionable knowledge base that informs climate-friendly policies and practices in Lower Saxony while serving as a model for other regions facing similar challenges. To learn more about our research, methodologies, and ongoing initiatives, visit urbanclimatefuturelab.de. Ultimately, we anticipate that the project will contribute significantly to advancing the field of sustainable urbanism, offering new insights and tools for building cities that are better equipped to face the impacts of climate change.

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