Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Climpact Typology: Towards a relational and climate impact driven classification of open space

Dag-Ole Ziebell
dag-ole.ziebell@freiraum.uni-hannover.de

Leibniz University Hannover
Martin Prominski
Leibniz University Hannover
Vanessa Carlow
Technische Universität Braunschweig
Deepank Verma
Technische Universität Braunschweig

Research Article

Keywords:

Posted Date: June 23rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9972103/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: No competing interests reported.

Abstract

Open space planning plays a significant role in adapting urban and rural spaces to climate change. Depending on how open space is conceptualized, its climate impacts may differ. Thus, understanding the relationship between landscapes and climate elements such as radiation, wind and precipitation is crucial for leveraging the role of open spaces in climate-adaptive strategies. In this study, we introduce the Climpact Typology, a method for classifying open spaces by their climate impact relative to their local spatial context. In three steps, ranging from qualitative description through operative mapping to quantitative classification of open space using agglomerative clustering, we reveal eight Climpact attributes and classify 26.818 open spaces into ten Climpact types. The Climpact Typology aims to bridge comparability and spatial relationality within a single framework and provides a practical, spatial-planning-oriented understanding of open spaces beyond anthropogenic land use to support climate-adaptive design and planning decisions.

1. Introduction

How humans conceptualize space determines the understanding, planning, and design of landscapes. Within contemporary academic discourse, there is criticism that the shift from cartographic representations to digital mapping and data-oriented thinking oversimplifies the heterogeneous character of landscapes due to the inherently homogenizing nature of digital data (Aït-Touati et al., 2022, p. 6). In the context of climate change, such abstractions may obscure the specific assemblage of actors, processes, and spatial conditions that co-produce local climatic effects. To better understand the complex interactions between climatic elements like radiation, wind or precipitation (Laue, 2019, p. 26) and open spaces, we develop a method for a climate impact typology (Climpact Typology) that classifies open spaces according to their context-specific climatic impact. Based on a mixed-method approach, the Climpact Typology provides a scalable yet locally sensitive framework and supports climate-adaptive and climate-mitigative spatial planning decisions.

1.1 Climate change and the role of open space

Human-induced climate change continues to threaten both human and non-human life on Earth. As one of the seven planetary boundaries that have already been breached, the ongoing climate change emphasizes the critical state of our planet (Calvin et al. 2023; Sakschewski et al. 2025). In urban areas, climate change impacts are particularly acute, as urban morphologies and infrastructure strongly influence local climate elements, amplifying heat stress, altered airflow, and hydrological variability (Laue 2019; Lenzholzer 2015; Pörtner et al. 2022; Oke et al. 2017). However, rural landscapes are also affected, as increased exposure to the climatic elements, such as radiation or wind, also contributes to climatic vulnerability. Open spaces, both urban and rural, play a significant role in planning under environmental conditions of climate change: if they are green, they can help ameliorate local climatic conditions through adaptation and mitigation, if they are grey, they may exacerbate thermal and hydrological stress. Drawing on Rittel and Webber's "General Theory of Planning", open space planning deals with 'wicked problems', which defy purely technical and rational solutions (Rittel and Webber, 1973, p. 161; Prominski, 2019, p. 33). Climate change is widely recognized as a "super wicked problem" (Lazarus, 2010, p. 1160), characterized by deep uncertainty, multiple interacting actors, and urgent time constraints. If we frame the complexity of open space planning and design in the context of climate change as a "super wicked problem," reducing this complexity to address uncertainty and provide an information basis for decision-making under time pressure may be beneficial. Therefore, understanding the climate impacts of urban and rural open spaces becomes crucial for evaluating the role of individual open spaces and facilitating spatial decision-making. Typologies, understood as a systematic approach of describing a phenomenon by breaking down its complexity into several categories with their differences and similarities, are widely recognized (Foroughmand Araabi, 2016, p. 12). Particularly, in open space design, where classification systems often provide actionable knowledge to guide planning and design interventions, the value of typologies has been used for a long time (Nohl, 1990; Larice and Macdonald, 2007, p. 251).

1.2 Limitations of data-oriented thinking

One of the key developments in landscape conceptualization is associated with the pioneering work of physical geographer Alexander von Humboldt (*Nature Ecology & Evolution*, 2019, p. 1265). Humboldt systematically documented how plant communities transition along altitudinal gradients in the Andes, reflecting corresponding shifts in climatic conditions such as temperature, humidity, and atmospheric pressure. His conceptualization of these zones, notably illustrated in the *Naturgemälde* of Mount Chimborazo in 1807, demonstrated the interplay between landscape morphology and climatic conditions, effectively establishing a prototype for climate-driven classification systems (Humboldt and Bonpland, 1807, p. 155). By combining qualitative description, drawing, and writing with quantitative measurements in a unified representation, Humboldt's approach remains threefold: it is locally specific and a mixed method that integrates both qualitative and quantitative analysis.

The sociologist and philosopher Bruno Latour highlights that, due to the technical constraints of his time, Alexander von Humboldt's scientific work was fundamentally grounded in situated observation. Humboldt's approach requires direct engagement with the landscapes under study (Bruno Latour, Peter Weibel, 2020, p. 8). This contrasts sharply with contemporary, data-driven representations of space, which frequently rely on standardized datasets and satellite imagery and often aim for a high level of abstraction. Latour contends that such remote conceptualizations of space inherently engender a sense of *disconnectedness* - a perspective also elaborated by the French architect Alexandra Arènes, who argues that "In such planetary view, where earth is viewed as if from out in space, all life forms as well as humans are squashed to the point of becoming invisible. This creates a cognitive dissonance since there is no commensurability between the lived experience […] and the image provided by the planetary view." (Arènes, Latour and Gaillardet, 2018, p. 4). While these data-centric methods enhance scalability and cross-contextual comparability at global and planetary scales, they may also diminish the visibility of local heterogeneity and the relational structures that define landscapes and their impact on climatic conditions. By underscoring the enduring relevance of site-specific observation for comprehending landscape complexity, Humboldt's work provides an essential way of thinking for our Climpact Typology. A synthesis of qualitative and quantitative methodologies - integrating site-specific observation of open space with contemporary data analytics - could mitigate the limitations of data-oriented thinking and planetary observation, including their tendency toward homogenous abstraction, thereby preserving the relational and experiential dimensions of spatial analysis.

1.3 Climate impact driven classification systems

In contemporary spatial research, landscape classifications are increasingly driven by data-intensive techniques, particularly remote sensing methods such as satellite imagery, which are processed and analyzed within Geographical Information Systems (GIS). These methods prioritize standardized cartographic metrics to ensure high comparability across regions and scales. A dominant focus in recent typologies is the classification of anthropogenic land use and land cover (LULC), where landscapes are differentiated from a distance based on quantifiable patterns - such as urbanization, agricultural expansion, or natural vegetation cover (Montero, Van Wolvelaer and Garzón, 2014, p. 152). The availability of high-resolution satellite datasets, including the U.S. National Land Cover Dataset (NLCD) (Homer et al., 2007, p. 337) and the CORINE Land Cover (CLC) program (Bossard, M., Feranec, J., & Otahel, J., 2000, p. 301), has further accelerated this trend, enabling globally consistent and publicly accessible spatial analyses. Land Cover datasets are particularly valuable for monitoring changes in landscape systems over time, especially in assessing the impact of climate change related hazards or urban development on a global scale. However, they are less effective at providing information about the actual climate impacts at the observed sites and focus on monitoring Earth's surface changes.

Besides land cover classifications, analytical frameworks increasingly incorporate the complex interplay between the urban built environment and prevailing climatic conditions, highlighting phenomena such as urban heat island effects, carbon sequestration potential, or flood risk to inform evidence-based spatial planning. These emerging typologies aim to position the climatic impact of urban and rural form into the core of classification processes, thereby supporting adaptive strategies in both urban and rural contexts. The Local Climate Zones (LCZ) framework, first introduced by Ian D. Stewart and Timothy R. Oke (2012) to analyze urban heat island effects, has gained widespread acceptance as a tool for comparing the climatic impacts of diverse urban morphologies on a global scale (Demuzere et al., 2022, p. 3837). The framework's 17 distinct zones, encompassing both urban and rural areas, are defined by standardized parameters that align with climate models, thereby serving as an intermediary between spatial planning and urban climate simulations (Stewart and Oke, 2012, p. 1893; Demuzere et al., 2022, p. 3852; Gál et al., 2025, pp. 2–3). While the LCZ system's fixed, site-independent parameters ensure high comparability and global applicability, they also inherently produce a homogenized representation of urban-rural systems that rarely reflects real-world complexity (Stewart and Oke, 2012, p. 1888; Verein Deutscher Ingenieure, 2024, p. 15). For instance, topography, a critical factor in local microclimates (Lenzholzer, 2015, p. 40; Laue, 2019, p. 30; Verein Deutscher Ingenieure, 2024, p. 3), remains unparameterized in the LCZ classification. Furthermore, while the framework conceptually positions urban and rural areas as a continuum rather than a dichotomy, its practical application remains overwhelmingly urban-centric, potentially marginalizing rural climate dynamics (Verein Deutscher Ingenieure, 2024, p. 15; Gál et al., 2025, p. 26).

Another climate-impact-driven classification of landscape is the climatope (Klimatope) framework, which defines spatial units characterized by similar microclimatic conditions. Developed as part of the climate analysis map (Klimaanalysekarte), this approach is an essential tool for spatial planning in Germany, enabling evaluation of climate-relevant elements such as temperature, humidity, and air exchange (Verein Deutscher Ingenieure, 2024, pp. 5–10). The Association of German Engineers (VDI) distinguishes nine climatopes, ranging from "city center climatope" to "open landscape climatope", including specialized categories such as forest climate, water climate, and open landscape climate (Ibid.). Unlike parameter-driven frameworks such as the Local Climate Zones (LCZ), climatopes are identified through a qualitative-descriptive process led by experts. While this classification is not derived from algorithmic datasets in the first place, it nevertheless relies on parameter-based information - including relief, land cover, and vegetation structure - which partially overlaps with LCZ criteria but places greater emphasis on relief features and open spaces (e.g., topography, slope exposure) (Stewart and Oke, 2012; Verein Deutscher Ingenieure, 2024, p. 4). This landscape-centric focus contrasts with the LCZ's urban orientation, as climatope explicitly incorporates forest, water, and rural open-space climates as distinct categories. However, case studies in Basel, Hanover, or Tiel reveal significant inter-study variability in climatope classification due to its qualitative nature (Scherer et al., 1999, p. 4186; Lenzholzer, 2015, p. 61; Kuttler and Weber, 2023, p. 17). While this flexibility enables context-sensitive adaptations, it also compromises comparability across regions, a critical limitation for standardized planning applications. Thus, despite its ecological and landscape-oriented strengths, the climatetope framework may be less suitable for large-scale comparative analyses than quantitative systems like LCZ. In summary, this section shows two different approaches to climate-impact-driven spatial classifications, comparing the qualitative climatope framework, rooted in expert-based microclimatic and topographic assessments (Verein Deutscher Ingenieure, 2024, p. 12), with the quantitative Local Climate Zones (LCZ), which rely on standardized, parameter-driven metrics (Stewart and Oke, 2012, p. 1884). While climatope captures local heterogeneity and landscape-specific nuances (e.g., forest, water, and relief-based climates), their subjective nature limits comparability across regions. Conversely, LCZs ensure global scalability but risk homogenizing complex spatial realities by neglecting topographic and ecological diversity. Drawing on Latour's critique of data-oriented thinking and Humboldt's mixed-method approach, we argue for a hybrid classification system that integrates climatopes qualitative depth with LCZ's quantitative rigor. Our Climpact Typology aims to preserve the local specificity of open spaces while enabling transregional climate impact assessments, addressing the tension between standardization and contextual sensitivity in spatial planning.

1.4 Drawing the Climate Sphere

Operative mapping, as conceptualized by Roger Páez (Paez, 2018, p. 21), extends beyond traditional cartography to embody a critical practice of spatial reasoning that actively shapes our understanding of complex environmental systems. This perspective aligns with James Corner's argument that mapping constitutes a tactical enterprise of relational reasoning rather than mere data accumulation (Corner, 2011, p. 100). Historical precedents such as Guy Debord's *The Naked City* (1957) and Kevin Lynch's *The Image of the City* (1960) demonstrate how operative mapping can reveal hidden spatial dynamics (Paez, 2018, p. 18). A recent example that embodies the principles of operative mapping is Terra Forma (Aït-Touati et al., 2022). With a strong connection to Actor Network Theory (ANT) (Latour, 2005) and the Gaia Hypothesis by Lynn Margulis and James Lovelock (Lovelock and Margulis, 1974; Lovelock, 2016; Bruno Latour, Peter Weibel, 2020, p. 178), Arènes developed a new form of inquiry to understand the complexity of the landscape through a new projection system. As a graphical representation for the critical zone - the thin layer of life between the lower atmosphere and saprolite (Arènes, Latour and Gaillardet, 2018, p. 2; Arènes, 2021, p. 1) - Arènes proposes the new method of Gaiagraphy to focus the attention on the soil and its relational exchanges of geochemical processes assessed by geoscientists (Arènes, 2021, p. 1).

Arénes inverts the conventional representation of soil layers and places the earth core at the outside of her Gaiagraphies, while placing the critical zone in the center. This creates a focus on the intricate web of local relational dynamics among living organisms, dynamics that remain invisible in the detached, top-down view of satellite imagery. Between scientific measurements of geoscientists and landscape architecture, Arènes invents: “a transitional tool to situate ourselves in this fragile skin of the Earth…”.(Arènes, 2021, p. 10). Without drawing the connection herself, Arènes representation could be interpreted as a match to Humboldt’s approach of qualitative description and quantitative measurement for a local and specific conceptualization of landscape. Over the past years, Gaiagraphy has become well established in the field of landscape architecture and has found applications beyond its original purpose (Kreis and Prominski, 2025, p. 29; Neuhaus, 2025, p. 14). This study aims to further expand the method by introducing the Climate Sphere, which flips Gaiagraphy’s original intention on its head. Instead of visualizing already assessed scientific data, we want to explore the method as an evaluative tool to identify which climate-impact attributes of open spaces should be prioritized for further assessment.

1.5 Climpact Typology – 3 Steps for a relational climate impact classification of open space

The synthesis of the climatope qualitative strengths and LCZ’s quantitative rigor, grounded in Latour's critique of data homogenization and Humboldt's mixed-method approach, aims to establish a robust theoretical foundation for a context-sensitive spatial classification of open space representative of their climate impact. To develop a method combines of qualitative description (local specific context) and quantitative measurement (comparability) within an integrative framework, we ask: *How can a data-oriented classification process maintain landscape heterogeneity while developing a local, relational, and actionable typology of open spaces based on their climate impact?*

In this research, we introduce the Climpact Typology, which addresses the research question through a three-step methodological approach. First, we establish the spatial context for the study area of Salzgitter by producing a Gaiagraphy, from which we derive climate impact attributes from the landscape’s climatic effects, while taking account of landscape heterogeneity.

In the second step, these attributes are calculated in Geological Information Systems (GIS) for each open space in the study area, providing a location-specific dataset for the classification process. Finally, in the third step, we classify the Climpact attribute table using hierarchical clustering to determine an appropriate number of open space types, granulated to a level suitable for actionable climate adaptation decision-making.

2. Methodology

Our Climpact Typology is part of the multidisciplinary research project Urban Climate Future Lab (UCFL), with the overall objective of investigating the interlinkages between urbanization and climate change in Lower Saxony, Germany. To align the case studies with the objectives of UCFL, the choice was limited to the federal state of Lower Saxony. UCFL aims to work with three case study areas distributed across the different climate-ecological zones of Lower Saxony (Coastal, Geest/Börde, Mountain-Foothill) (Thomas Mosimann, Thorsten Frey, Peter Trute, 1999, p. 219; Elbracht et al., 2020, p. 17) (see Fig. 01). The strategic distribution centers the complex interplay of settlement and landscape structure with local specific climatic conditions and delivers a spatial framework that represents Lower Saxony’s versatility in urbanization and landscape morphology. To prototype the Climpact Typology framework, we chose the case Study of Salzgitter, a representative of Lower Saxony's Mountain Foothill region (see Fig. 02).

The administrative boundary of Salzgitter covers 224 square kilometers, making it the largest independent city in Lower Saxony and the seventh largest in Germany by area. This can be explained through Salzgitter’s rather unique history. Unlike most cities, Salzgitter is not a historically evolved urban center but was established in 1942 through the merger of 28 rural communities and the small town of Salzgitter. So it can be explained that, given its size, the population density remains low at 485.7 inhabitants per square kilometre. Unlike most cities, Salzgitter is not a historically evolved urban center but was artificially established in 1942 through the merger of 28 rural communities and the small town of Salzgitter. Today, Salzgitter stands as Germany’s only city with a decentralized urban agglomeration in a single administrative city border, comprising 31 isolated settlement units - mostly small villages, with the exceptions of Salzgitter-Lebenstedt and Salzgitter-Bad (State Office for Statistics Lower Saxony, 2007), which form the urban cores of the settlement. This fragmented and diverse settlement structure provides a rare opportunity to study open spaces along the urban-rural gradient, their climate impact, and interlinkages with different settlement structures within a single case study.

Salzgitter’s land use is particularly notable: 51.2% of the area is agricultural, 16.6% forest, 3% recreational, and 28.5% dedicated to settlement and mobility infrastructure (Ibid). This distribution creates a mosaic of open spaces with varying climate-impact attributes, ranging from agricultural fields and forests to recreational areas. The decentralized settlement pattern further amplifies the interaction between built environments and these open spaces, allowing for a nuanced analysis of how different open spaces influence local climate conditions. As the example of the mountain foothill area, Salzgitter’s landscape is shaped by the elevation of the Salzgitter Ridge, an extension of the Harz Mountains. Reaching up to 322.9 meters above sea level (OpenGeoData Lower Saxony, 2026) and supporting diverse flora and fauna, the higher foothills are not only a protected landscape in Lower Saxony but also an important source of cold, fresh air (Lower Saxony Ministry for the Environment, Energy, Building and Climate Protection, 2021). Due to its rich mineral resources, such as iron ore, mining played a significant role in Salzgitter’s settlement history (Röhling et al., 2018). This historical influence is still evident today in the city’s large legacy industrial sector, which accounts for 10% of entire Lower Saxony’s annual CO_2 emissions, although the population of Salzgitter is only 1,3% of Lower Saxony (Salzgitter City, 2026, p. 1)

The combination of decentralized urbanization, topographically influenced climate, and diverse settlement and landscape structures shaped by industrial and agricultural infrastructure exemplifies the mountain foothill zone of Lower Saxony. This unique configuration provides an open space structure that is not only suitable for investigating the climate impact of open spaces but also for developing a classification system grounded in locally specific landscape characteristics while ensuring regional comparability. To develop the prototype of our Climpact Typology in the Case Study of Salzgitter, we conduct three methodological steps:

1. *Relational determination of Climpact Attributes by mapping the Climate Sphere*
2. *Assessment of Climpact - from Climpact attribute to attribute table*
3. *Classification of Open Spaces in Climpact Types*

2.1 Relational determination of Climpact attributes by mapping the Climate Sphere

To evaluate the relevant Climpact attributes of open spaces, the first step of the Climpact Typology is to map the complex interplay of climate elements and landscapes within Salzgitter. This is achieved by applying two cornerstones of research through design, the reflective and projective moments (Prominski, 2019, pp. 36–37), to a mapping process within the Gaiagraphy's projection system (Arènes, 2021, p. 11; Aït-Touati et al., 2022, p. 40). The reflective moments represent a critical literature review and case-study analysis, unfolding established parameters in spatial planning to describe the climate impacts of open space and the context-specific landscape characteristics of Salzgitter. The projective moments reveal the complex interplay between climate elements and Climpact attributes through speculative mapping of the local climatic system of Salzgitter, which we name the Climate Sphere. We use the layout of Gaiagraphy (Soil Mode) as a projection system for the Climate Sphere (Aït-Touati et al., 2022, p. 40). Therefore, we follow the three methodological steps provided by Alexandra Arénes to change the planetary view of Salzgitter into a Gaia-Perspective (see Fig. 3): First, the globe's cross-section is adopted as the basis, with its layers from the Earth's core to the atmosphere remaining intact. By reversing the order of these layers, the atmosphere is placed at the center and the Earth's core at the outer edge. This enables prioritization of the thin layer of life, where climate elements and Climpact attributes interact, and which is often underrepresented in other planning-informative visualizations. Secondly, we establish the point of reference, which defines the specific part of the critical zone under observation. In our case, the reference is not a single point but the entire area of our case study - Salzgitter. This approach allows us to consider the spatial and relational dynamics of the critical zone across the whole region, rather than limiting our analysis to a localized point. In a last step, we arrange the earth strata according to our research objective. In evaluating Climate attributes, we focus on the lower atmosphere and the surface, where most Climate attributes interact with climate elements; however, the other strata layers remain because geological resources and topography influence the Climate Sphere of Salzgitter. Here, we depart from the original Gaiagraphy (Soil Model), which emphasizes the strata that highlight the soil's geochemical processes. Furthermore, our intention in using this projection system, which highly emphasizes complexity and spatial dynamics, differs from that of its inventors. Originally, Gaiagraphy was introduced as a method for representing scientific results from geoscientists (Arènes, 2021). Just as the method inverts Earth's strata, we invert the method's purpose. Instead of displaying results assessed by scientists, we propose revealing a yet undiscovered potential by using the novel perspective of the Gaiagraphy as a platform for research through design to investigate which data needs to be assessed. The iterative application of nonlinear reflective and projective moments (Prominski, 2019, p. 39) enables a deeper understanding of the complex interplay of climate elements and open spaces in the mapping process. This is particularly helpful for addressing the proposed research question because it enables an evaluation process to determine which attributes should be assessed to classify open spaces according to their climate impact and simultaneously grounds this process in relationality with the local specific context.

2.2 Assessment of Climpact – From attribute to attribute table

To classify the Climpact of open spaces in Salzgitter, we built upon our initial methodological step by calculating a set of Climpact attributes evaluated by the mapping process of the Climate Sphere. These attributes were quantified using Geographical Information Systems (GIS), enabling the development of a comprehensive database for classifying open spaces. Our analysis included all open spaces within the administrative boundaries of Salzgitter. The unique urban form and fragmentation of Salzgitter allowed us to represent both rural and urban open spaces within a single case study, providing an integrative perspective on their interdependencies and climate functions.

We utilized the Official Land Registry Information System (ALKIS) Land Use Dataset (ETRS89 / UTM Zone 32N, EPSG:25832) as our basic spatial unit, provided by the State of Lower Saxony. The dataset was selected for its high precision and relevance in regional and spatial planning. By including every polygon in the vector-based land-use ALKIS dataset in the analysis, we ensured a consistent analytical framework that captures not only the morphological, functional, and climatic interdependencies among all spaces in our database but also the influence of buildings on the climate impacts of open space. This approach facilitates the integrated analysis of 26,818 open spaces in Salzgitter, encompassing both urban and rural areas.

To calculate the Climpact attributes, we employed a combination of publicly available raster and vector geodatasets, prioritizing regional or national datasets where possible. Global datasets, such as Landsat 9, were used only when regional or national data were insufficient. In total, eight datasets (including ALKIS) were integrated into the assessment process (see Table 01).

2.3 Classification of Open Spaces in Climpact types

In the preceding steps, Climpact attributes were identified and assessed within the Salzgitter case study area. The intermediate results served as the database for subsequent classification into Climpact types. To construct these Climate types, a hierarchical clustering method was employed to reveal similarities among data points in the Climpact dataset. This is a known approach to developing classification schemes that has already been used to investigate spatial patterns with the TOPOI-method (Carlow et al., 2022, p. 10; Verma, Mumm and Carlow, 2022, p. 12). Hierarchical clustering methods differ in agglomerative (bottom-up) and divisive (top-down) strategies. We chose a bottom-up method in which data points represent initial clusters and are iteratively merged with their nearest neighbours until a single cluster remains. The analysis was implemented using the SciPy library (Virtanen et al., 2020) with ward linkage applied to determine the distances between clusters (Verma, Mumm and Carlow, 2022, p. 12). A key advantage of this approach is the visualization of cluster fusion through a dendrogram, which illustrates how clusters merge at varying levels of similarity. The visualization shows the number of data points in each cluster and their proximity to the main branches (see Fig. 07). Given that the embedding spread does not reveal distinct clusters, the approach involved applying different cutoff distances to visually assess whether meaningful structural differences between clusters become apparent. The dendrogram can be "pruned" at the point where the number of clusters appears most meaningful for the typology, given the spatial context, allowing the selection of an optimal number of Climpact types based on the fusion of clusters and cluster distances.

3. Results

The application of the Climpact Typology method resulted in eight Climpact attributes for Salzgitter and the Mountain Foothill region. Using conventional ArcGIS tools for spatial calculations, such as zonal statistics (Esri, 2026), the Climpact attributes for Salzgitter's open spaces were computed, analyzed, and visualized in maps. The values of the 26,818 surveyed open spaces were compiled into an attribute table and, in a final step, classified using a hierarchical clustering algorithm. The algorithm resulted in 65 initial clusters. By pruning the dendrogram at a cluster distance of 75, we identified 10 novel open space types (Climpact types), an appropriate number and level of differentiation for the spatial context of Salzgitter. We identified subtypes of the 10 Climpact types by following the dendrogram's cluster fusion to a cluster distance of 75, at which the number of open space types doubled, yielding 20 Climpact types.

3.1 Salzgitters Climate Sphere

The Climate Sphere illustrates the complex interplay of Salzgitter's landscape and prevailing climate elements. By projecting the findings from the literature and case study analysis onto Salzgitter's Climate Sphere (see Fig. 05), we enabled an iterative reflection process that yielded a more coherent and systematic understanding of Salzgitter's landscape and its climate impacts. This was significantly helpful to identify eight Climpact attributes relevant to the case study area's specific context (see Table 02). By selecting the Climpact attributes through spatial analysis and expert judgment within a novel projection system, we establish the Climpact Typology based on qualitative descriptions of the spatial relationships between landscape and climate.

3.1.1 Qualitative description of the complex interplay between landscape and climate elements

The Climate Sphere features five different Landscapes in Salzgitter (ridge, open landscape, settlement, industrial landscape, post-industrial landscape) and represents their climate impact and interconnected relations with prevailing Climate elements. The **ridge** highlights the strong influence of topography on the local climate of Salzgitter. As a forerunner of the Harz Mountains (Look, 1985) with up to 90–150 m height difference to surrounding valleys, the ridge is the main driver in cold air production and an intake area (Lenzholzer, 2015, p. 40; Salzgitter City, 2021, p. 34). The rich forest structure that covers the ridge supports this function and enables cold air outlet through valley wind systems. The cold airflow has the potential to reach the nearby settlement structures and ventilate Salzgitter's urban environment on hot summer days. This cooling effect is reinforced by Salzgitter's unique urban structure, which has a high influence on the Climate Sphere. As Lower Saxony's only city with a decentralized urban structure, a large proportion of Salzgitter's area is covered by **open landscape**. The flat and permeable open landscape enables local winds to exchange and provides optimal wind exchange rates. Often situated between a cold-air producer such as the Salzgitter Ridge and a settlement, the open landscape acts as a corridor, enabling ground-level transport of air masses. However, they also provide fresh air themselves due to permeable surface characteristics and water storage (VDI 3787-1, 2024). While daytime evapotranspiration from the open landscape has a cooling effect, at night, the cold air from the surrounding hills is channeled towards the built-up areas. The structure of the **settlement** shows the typical open landscape/urban environment difference, caused by the build-up environment. With a high proportion of sealed surface area and a building stock ranging from detached houses on the outskirts to terraced houses and block developments in the center, the Climate sphere indicates an increase in temperature within the settlement structures. The impact of the dense build-up areas represents a typical Inner City climatope (Laue, 2019), known for the urban heat island effect. The **industrial landscape** of the Climate Sphere represents Salzgitter's large industrial sector. Like the settlement, these areas exercise a strong influence on the Salzgitter climate sphere due to their surface and building characteristics. In addition, the manufacturing processes at many industrial power plants in Salzgitter generate heat as part of their production. In some parts of Salzgitter, **post-industrial landscapes** can be found because of the cessation of mining activities. Owing to their biodiversity, structural richness, and, in some cases, protected status (Ministery of Environment, Energy and Climate protection, 2009), these landscapes exert a particular influence on the Climate Sphere. Often surrounded by open landscapes, these landscapes have the potential to extend the cold air they produce beyond their boundaries.

3.1.2 Identifying of Climpact attributes

This analysis of Salzgitter's landscapes and their interactions with climate elements are the basis for identifying Climpact attributes. By integrating qualitative visual descriptions and spatial data, the Climate Sphere enables us to interpret and assess relevant attributes for the case study area. To capture the interference of different vertical landscape structures, like the ridge or settlement, we assess surface **roughness**, a well-known parameter in spatial planning to calculate the influence of landscape characteristics on airflow (Lenzholzer, 2015; Oke et al.). To underscore the significance of the ridge elevation, **slope** emerges as a Climpact attribute to not only describe the potential for valley wind systems but also for water runoff (Lenzholzer, 2015). From the open landscape, we derive the attribute of **permeability**, distinguishing sealed from unsealed surfaces. We address the built-up environment of the settlement and industry by supplementing the **permeability** attribute with the **build-up area**, which highlights the climatic influence of buildings on open spaces. We selected **low surface temperature** (LST) as a Climpact attribute to indicate the heating potential of materials in landscapes. Most of the cooling potentials in Salzgitter's Climate Sphere derive from a combination of enabling local wind and vegetation structure. As a Climpact attribute that represents the many beneficial contributions of green infrastructure, we decided to assess the **canopy cover**. The decision was partly made due to the influence of canopy cover on the Salzgitter ridge and the settlement structure, and to the increased attention the parameter received from the 3-30-300 guideline (Konijnendijk, 2023; Bertassello et al., 2026). A framework that suggests three trees visible from every real estate, 30 percent canopy cover in cities, and a recreational park in a 300-meter distance from home. Salzgitter's fragmented settlement structure, with diverse land uses ranging from industry to agriculture, results in open spaces of varying sizes. Since size may increase climate impact (Kirschner et al., 2023), we included **open space size** as a Climpact attribute. This is particularly useful for determining differences between urban and rural open spaces, since the size of open spaces often varies along the urban-rural gradient due to housing pressure and agricultural land use. In addition, the Climpact Attribute **population count** indicates whether an open space is associated with a housing situation.

The selection of eight Climpact attributes (see Table 02), tailored to Salzgitter's Climate Sphere, is a cornerstone of the conceptual foundation of our Climpact Typology. By qualitatively analyzing spatial and climatic interdependencies, we have established a context-sensitive starting point for classifying open spaces in Salzgitter. This framework not only anchors the typology in local conditions but also sets the stage for quantitative evaluation: In the following paragraph, we translate these attributes into measurable parameters and calculate their spatial distribution to create an evidence-based database. The database will serve as the basis for classifying Salzgitter's open spaces into distinct Climpact types, enabling targeted climate-adaptive planning strategies.

3.2 Climpact attribute performance across Salzgitter

The interim result from our qualitative analysis of Salzgitter's Climate Sphere embodies eight Climpact attributes to describe the climate impact of Open Spaces in the mountain foothill zone of Lower Saxony. In this section, we present the results from methodological step two of the Climpact Typology, which transforms the findings of the eight Climpact attributes into a GIS attribute table by computing them for our representative case study, Salzgitter. The calculation of Climpact attributes bridges the qualitative description of the Climate Sphere in Step one and the data-oriented thinking in Step three, where we classify Salzgitter's Open spaces according to their climate impact with a hierarchical cluster algorithm. In addition, each attribute is mapped to visualize its spatial distribution and performance across the study area (see Fig. 05–06).

The analysis of **open space size** (see Fig. 06G) reveals a clear pattern along the urban–rural gradient. Open spaces within settlement structures are generally small and numerous, whereas those in the open landscape and forested areas are fewer but significantly larger. This distribution reflects the fragmented urban structure of Salzgitter.

Street landscapes represent a special case: although functionally continuous, they appear highly fragmented due to their linear geometry and the polygon-based structure of the ALKIS dataset. In contrast, agricultural open spaces range from 12.8 to 50.8 hectares, while forest areas, particularly in the Salzgitter ridge and eastern Lebenstedt, reach sizes of up to 151 hectares. An extreme outlier is the Salzgitter Company site, covering 557 hectares, representing one of the largest contiguous industrial areas in the city.

The Climpact attribute **slope** (see Fig. 05B) highlights the pronounced topographical contrast between the elevated Salzgitter ridge and the surrounding flat open landscape. Open spaces in the ridge exhibit mean slopes of up to 24°, whereas those in the open landscape range between 0 and 4°. Beyond this general contrast, high slope values also occur within industrial areas, such as sintering plants and landfills, where anthropogenic landforms create distinct topographical features. An additional finding is the relatively high slope performance of roadside greenery, often shaped by ditches or embankments associated with transport infrastructure.

In contrast to slope, the calculation of surface **roughness** (see Fig. 05A) incorporates not only terrain but also vertical structures such as buildings and vegetation. While the ridge/flatland contrast remains visible, high roughness values are particularly evident in settlement areas and industrial zones. These areas, characterized by dense vertical structures, act as barriers to air exchange. Conversely, the low roughness of the open landscape indicates a high potential for ventilation and air movement. The spatial variability of roughness across Salzgitter highlights the significant influence of vertical structures on local climatic conditions.

The **canopy cover** (see Fig. 06F) data reflects the approximately 16% forested land in Salzgitter, with coverage values between 77% and 100% in the ridge area. These forested zones function as key cold air production areas and significantly influence adjacent settlement climates. Within settlements, high canopy cover is mainly found at the urban periphery, marking transitions to agricultural landscapes. Isolated forest patches in the open landscape also contribute to the fresh air supply. In contrast, the low canopy cover (0–9%) in large parts of the open landscape supports their role as corridors for local and prevailing wind flows.

Permeability (see Fig. 05C) captures multiple interactions between climate elements and spatial structure. It indicates infiltration potential, surface runoff behavior, and the thermal properties of sealed versus unsealed surfaces. In Salzgitter, permeability shows a strong contrast between settlement and industrial areas on the one hand and the open landscape and ridge on the other.

In residential areas, open spaces are often sealed by up to 35%, particularly in low-density housing. In central areas, sealing intensifies and can reach up to 100%, a condition that also shows in Salzgitter's road networks. Industrial areas display a wide range of sealing degrees, with values up to 82%, although the extensive Salzgitter company site shows a comparatively moderate sealing of 46%. Lower permeability is generally associated with increased surface heating and water runoff, reinforcing its relevance as a Climpact attribute.

The **build-up area** (see Fig. 5D) attribute specifically highlights the built environment by quantifying the proportion of surfaces covered by buildings. High values are concentrated in settlement and industrial areas, particularly in the centers of Salzgitter-Bad and Lebenstedt. At the same time, the dataset reveals a defining characteristic of Salzgitter's urban structure: a large proportion of open spaces remain largely free of buildings. Approximately 22,905 out of 26,818 open spaces fall within the 0–10% sealing range, emphasizing the spatial openness of the urban fabric.

Population data (see Fig. 6H), derived from the 2015 German census with a spatial resolution of 1 hectare, was assigned to each open space. Despite its coarse resolution, it enables the identification of general settlement patterns and integrates human exposure into the analysis of climatic effects. The population is particularly useful to distinguish between residential and non-residential areas, which is essential for classifying climate impacts.

The analysis identifies 31 settlement areas, with the highest population densities in Lebenstedt and Salzgitter-Bad, followed by Gebhardshagen and Thiede. However, due to resolution limitations, misallocations occur in transitional zones, where uninhabited open spaces may be incorrectly assigned population values.

Land Surface Temperature (see Fig. 06E) is used to assess the thermal behavior of open spaces. Although air temperature at 2 meters height is often preferred for human-centered analyses, LST provides valuable insights into the heating potential of surface materials. Based on Landsat 09 data for a representative summer day, the analysis shows that 44.04% of open spaces exhibit high heat potential.

This high proportion is partly due to the large number of small open spaces within settlement areas. In contrast, large industrial open spaces show particularly high LST values, emphasizing their role in the urban heat island effect. At the same time, the differentiation of LST values supports the identification of both heat-prone and cooling-effective open spaces, contributing essential information for the subsequent classification.

The combined analysis of Climpact attributes reveals a strongly differentiated spatial structure shaped by Salzgitter's urban development. Settlement areas are characterized by small, fragmented open spaces with high sealing, high roughness, and elevated heat potential, leading to limited ventilation and increased thermal stress (Oke et al., 2017). In contrast, the open landscape and forested areas consist of larger, more continuous spaces with low roughness, high permeability, and significant cooling and ventilation functions.

Industrial areas occupy an intermediate but critical position: while often large in size, they exhibit high heat potential and variable sealing, making them key contributors to urban climate dynamics.

The interaction of topography (slope), surface structure (roughness), vegetation (canopy cover), sealing (permeability and built coverage), thermal properties (LST), and human exposure (population) provides a multidimensional understanding of open spaces and their climate impact.

3.3. Classification of Climpact types

The hierarchical cluster algorithm with Ward linkage (SciPy, 2026) initially identified 75 clusters among the 26,818 open spaces assessed in the Climpact attribute table of Salzgitter. By pruning the dendrogram at a cluster distance of 125, we detected ten novel Climpact types (see Table 03). The cluster distance allows scaling the number of open spaces, which is practical as it enables the quantity of open spaces to be adapted to the local spatial context as needed. Since this research focuses on the methodology of the Climpact Typology, we concentrate on the manageable ten Climpact types that emerge at a cluster distance of 125. If we consider the subtypes that develop at cluster distance of 100 and 75, the original ten clusters could be expanded to thirteen and twenty open space types, respectively.

A major advantage of the hierarchical cluster algorithm is the visual dendrogram, which makes it possible to trace where related data clusters fusion at specific distances (see Fig. 07). Each Climpact type represents different climatic effects, as the dataset on which the clustering method was applied is aligned with context-specific climatic impacts (see Fig. 08).

Climpact type one and type two describe inhabited open spaces in settlement areas. However, they differ in size, degree of sealing, building density, and canopy cover. While Climpact type one represents an open space with loose row house development, high population density, low sealing (average 30%), and over 20% canopy cover, Climpact type two has smaller areas with higher sealing and a lower degree of cover. Although the two residential open space types differ significantly in their values, their median roughness and heat potential are nearly identical. In Salzgitter, Climpact type one was identified only 78 times and is mostly located in central areas with high performance in low surface temperature (LST). In contrast, Climpact type two extends across the entire settlement areas of Salzgitter, whereas type one is found only in the larger settlement structures (see Fig. 08).

Climpact type three, on the other hand, describes small-scale, linear open spaces characterized by high sealing and the absence of vegetation and buildings, combined with low roughness values. This open space type is ubiquitous in Salzgitter and, in many cases, represents road spaces. In contrast, Climpact type fouris far more diverse in its vertical and horizontal structure. Mostly located at the urban periphery, its defining features are a mixture of maximal permeability and low canopy cover, as well as low roughness. Due to its location, this open space type is particularly suitable for channeling wind movements from open landscapes, largely represented by Climpact type five, into settlement areas. Statistically, types four and five are very similar; only the higher median LST in type four and its smaller size significantly distinguish these two open space types.

The extensive forest structures in Salzgitter, particularly on the Salzgitter Ridge, are assigned to Climpact type six. With high roughness, very dense canopy cover, and maximum permeability, this open space group fulfills the classic role of a cold-air producer. However, the addition of a high slope value also describes the influence of the mountain-foothill region and the typical slope and valley wind systems. The cooling role of Climpact type six is also reflected in the LST values, which are the lowest in this open space type.

Climpact types seven and eight are clusters with extreme values and very low numbers of open spaces. While type seven represents only one open space, type eight includes five representative open spaces in Salzgitter. The data suggest that these are due to extreme values in open space size (see Table 03). In Climpact type seven, the by far largest open space in Salzgitter is found, which also has the highest LST values. In contrast, the five open spaces in type eight have a median size of only 2.4 m². Although both classifications are meaningful based on their underlying data and a clear difference from other open space types emerges for the hierarchical cluster algorithm, it must be critically questioned, particularly in the case of Climpact type eight, whether such extreme values can make a meaningful contribution to the goal of the Climpact typology, namely supporting spatial planning decisions.

The last two Climpact types, nine and ten, both have low sealing and low LST. They are neither inhabited nor characterized by buildings. The decisive differentiation lies in the high slope values that characterize Climpact type nine and the high canopy cover that defines type ten. While type nine is mostly linear in shape and represents roadside greenery or railway infrastructure, where high terrain variability is evident through noise barriers or drainage ditches, type ten features park-like vegetation structures with low sealing.

4. Discussion

The Climpact Typology bridges qualitative mapping and data-driven analysis through a three-step methodology, expanding the established ALKIS dataset for Lower Saxony to develop an open-space typology driven by climate impacts. By selecting Salzgitter as a representative case study for the mountain foothill region of Lower Saxony, the derived Climpact attributes and Climpact types demonstrate applicability within the boundaries of this climate-ecological region. The typology strives to balance the quantitative aspects of Local Climate Zones (LCZs) with the qualitative aspects of climatopes, focusing on regional landscape characteristics and comparable climatic conditions. To extend its applicability across all of Lower Saxony and beyond, the methodological framework must be applied to the remaining landscapes, coastal areas and Geest/Börde regions, where new Climpact attributes and types are expected to emerge due to varying landscape conditions. This approach could particularly benefit regional planning by providing a unified database for climate-adaptive planning across all municipalities in Lower Saxony, thereby supporting the German government's goal of establishing climate adaptation concepts in 80% of obligated municipalities (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz, 2023, p. 6).

The earlier-mentioned limitation of data-oriented thinking (Aït-Touati et al., 2022) is addressed by integrating case-study-specific landscape characteristics and their complex interplay with climate elements within the climate sphere. Inspired by Humboldt's mixed method and site-specific approach (Bruno Latour, Peter Weibel, 2020), the methodology ensures that the individual character of the case study informs subsequent data analysis and classification. While the calculation of Climpact attributes involves abstraction, their origins in qualitative descriptions of local climate elements remain a defining influence. The Climpact Typology, like any classification system, cannot fully capture Salzgitter's complexity. Yet, as a compromise between relationality and comparability, it offers a robust foundation for climate-adaptive planning grounded in the case study's local context. The differentiation between Climpact types not only supports a spatial understanding beyond landuse types but also provides a significant database. This combination could make the Climpact Typology a valuable asset for climate-adaptive master and land use plans.

The adoption of Gaiagraphy's alternative projection system enables a systematic representation of the interplay between climatic conditions and open spaces, highlighting the complex inderdependencies of landscape and climate elements. However, the reflective moments (Prominski, 2019, p. 36) in the case study analysis introduce a potential bias, as the quality of the climate sphere depends on the researcher's interpretation. Recent studies (Kreis and Prominski, 2025, p. 30) highlight the effectiveness of Gaiagraphy in co-production and transdisciplinary processes, which can reduce individual biases through collaborative workshops.

A key challenge arises in translating Climpact attributes into GIS attribute tables, particularly when using the vector-based ALKIS dataset as the basic spatial unit. In urban areas, open spaces like parks may be fragmented into multiple polygons, complicating their classification. Additionally, low-resolution datasets (e.g., German census data with 1-hectare resolution) (Statistisches Bundesamt, 2022) can introduce inaccuracies in the classification process. While these issues may hinder the typology's applicability in planning procedures, they can be addressed through post-processing; however, we omitted this step in our study to maintain focus on the prototypical application of the methodology. Another critical factor is the currency of the underlying datasets; to prevent discrepancies between the open space typology and the actual landscape, the Climpact Typology must be updated regularly.

Despite these limitations, the Climpact Typology provides a clear, actionable representation of the climate impacts of Salzgitter's open spaces through its ten novel Climpact types. The hierarchical clustering of the collected datasets is particularly effective, as the dendrogram enables a context-specific selection of Climpact types. For instance, the number of Climpact types can be adjusted based on the scale of analysis: ten to thirteen types at a cluster distance of 125 to 100 may suffice for urban planning, while a cluster distance of 75 can differentiate 20 types across broader climate-ecological regions. Overall, the ten proposed Climpact types provide a comprehensive information base for planning decisions. Furthermore, the Climpact Typology enables more efficient rollout of tested climate adaptation solutions to similar types.

However, extreme values in the clustering process, such as those in Climpact types seven and eight, pose challenges. While methodologically sound, these types may limit comparability because of their small sample sizes. In Salzgitter, the inclusion of the Salzgitter Company area in type seven is justified by its climatic relevance and size, whereas type eight (median area: 2.4 m²) has negligible significance for climate impact and planning. Adjusting the cluster distance could merge or further divide such extreme types, but a depth of 200, required to combine types eight, nine, and ten, would reduce the typology to just five types, compromising its explanatory power and abstracting the climate impact of open spaces.

5. Conclusion

The Climpact Typology addresses a critical gap in contemporary spatial discourse: the risk that data-driven conceptualizations homogenize the heterogeneous character of landscapes, a critique prominently articulated by Bruno Latour (Aït-Touati et al., 2022). We addressed the proposed research question by developing a relational, mixed-methods framework. Our typology minimizes abstraction through an innovative three-step methodology that bridges qualitative description and quantitative measurement, classifying open spaces by their context-specific climatic impact. Applied to Salzgitter, the method demonstrates how the local multiplicity of prevailing climatic processes and spatial conditions can be preserved within a system that is scalable beyond Salzgitter's boundaries. Compatible with established datasets like ALKIS, the Climpact Typology transcends its regional origins, offering a universally adaptable tool for climate-adaptive planning. This also shows in the number of Climpact types, which can be adapted to different levels of spatial granulation and provide therefore a value for different planning instruments like landscape plans, master plans or land use plans. Finally, the methodology yielded a set of ten novel Climpact types and eight relational Climpact attributes, which will be further developed and applied to the other two climate-ecological regions of Lower Saxony in upcoming research.

Declarations

Author Contribution

DZ conceptualized the research, designed the methodology, created the visualizations, performed the GIS data assessment, and led the writing of the manuscript. MP contributed to the research design and writing. VC participated in the writing process and provided critical reviews. DV conducted the hierarchical classification of the dataset.

Acknowledgement

This work is part of the interdisciplinary research project Urban Climate Future Lab and was supported by the Niedersächsisches Ministerium für Wissenschaft und Kultur (MWK) under the program 'zukunft.niedersachsen'. We are grateful to Eurac Research for the opportunity to present our findings at the 'Smart and Sustainable Planning for Cities and Regions' conference. We also extend our thanks to Ryan Zeringue and Esteban Muñoz for their critical feedback on this research.

Data Availability

The Climpact Typology was conducted only with publicly available data:List of Datasets and where to find them:Digital terrain model: https://ni-lgln-opengeodata.hub.arcgis.com/apps/lgln-opengeodata::digitales-gel%C3%A4ndemodell-dgm1/aboutDigital surface model:https://ni-lgln-opengeodata.hub.arcgis.com/apps/lgln-opengeodata::digitales-oberfl%C3%A4chenmodell-dom1/aboutSealed surface cadastre: https://entsiegelungskataster.niedersachsen.de/Aerial imagery OpenGeoData Lower Saxony:https://ni-lgln-opengeodata.hub.arcgis.com/apps/lgln-opengeodata::digitales-orthophoto-dop/aboutAerial imagery Landsat OLI 9:https://earthexplorer.usgs.gov/ALKIS Dataset:https://ni-lgln-opengeodata.hub.arcgis.com/apps/lgln-opengeodata::alkis/aboutUrban Green Raster:Krüger, T. et al. (2022) “Urban Green Raster Germany 2018”. Zenodo. doi:10.26084/ioerfdz-r10-urbgrn2018.Census Data: https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/Zensus2022/_publikationen.html#1403950

References

1. Aït-Touati F et al (2022) *Terra forma: a book of speculative maps*. Translated by A. DeMarco. Cambridge, Massachusetts London: The MIT Press
2. Arènes A (2021) ‘Inside the Critical Zone’, *GeoHumanities*, 7(1), pp. 131–147. Available at: https://doi.org/10.1080/2373566X.2020.1803758
3. Arènes A, Latour B, Gaillardet J (2018) ‘Giving depth to the surface: An exercise in the Gaia-graphy of critical zones’, *The Anthropocene Review*, 5(2), pp. 120–135. Available at: https://doi.org/10.1177/2053019618782257
4. Bertassello LE et al (2026) ‘Assessing European cities with the 3-30-300 rule underscores the need for enhanced urban greening efforts’, *Nature Communications* [Preprint]. Available at: https://doi.org/10.1038/s41467-026-71523-8
5. Bossard M, Feranec J, Otahel J (2000) ‘CORINE Land Cover Technical Guide’, *European Environment Agency*, 40. Available at: https://www.scirp.org/reference/referencespapers?referenceid=3501924 (Accessed: 11 May 2026)
6. Latour B (2020) Peter Weibel ‘Critical Zones - The Science and Politics of Landing on Earth’, *Center for Art and Media Karlsruhe* [Preprint]
7. Bundesministerium für Umwelt Naturschutz, nukleare Sicherheit und Verbraucherschutz (2023) *Bundes-Klimaanpassungsgesetz*
8. Carlow V et al (2022) ‘TOPOI -A method for analysing settlement units and their linkages in an urban-rural fabric’, *Environment and Planning B Urban Analytics and City Science*, 49, pp. 1663–1681. Available at: https://doi.org/10.1177/23998083211043882
9. Corner J (2011) ‘The Agency of Mapping: Speculation, Critique and Invention’, in M. Dodge, R. Kitchin, and C. Perkins (eds) *The Map Reader*. 1st edn. Wiley, pp. 89–101. Available at: https://doi.org/10.1002/9780470979587.ch12
10. Demuzere M et al (2022) ‘A global map of local climate zones to support earth system modelling and urban-scale environmental science’, *Earth System Science Data*, 14(8), pp. 3835–3873. Available at: https://doi.org/10.5194/essd-14-3835-2022
11. Elbracht DJ et al (2020) ‘Klimawirkungsstudie Niedersachsen&#8217
12. Esri (2026) ‘Zonal Statistics (Spatial Analyst)—ArcGIS Pro | Documentation’. Esri. Available at: https://pro.arcgis.com/en/pro-app/3.6/tool-reference/spatial-analyst/zonal-statistics.htm (Accessed: 8 June 2026)
13. Foroughmand Araabi H (2016) ‘A typology of Urban Design theories and its application to the shared body of knowledge’, *URBAN DESIGN International*, 21(1), pp. 11–24. Available at: https://doi.org/10.1057/udi.2015.6
14. Gál T et al (2025) ‘A Structured Literature Review of the Application of Local Climate Zones (LCZ) in Urban Climate Modelling’, *Earth*, 7(1). Available at: https://doi.org/10.3390/earth7010003
15. Homer CG et al (2007) Completion of the 2001 National Land Cover Database for the conterminous United States. Photogram Eng Remote Sens 73(4):337–341
16. Humboldt A (1807) von and Bonpland, A. *Ideen zu einer Geographie der Pflanzen: nebst einem Naturgemälde der Tropenländer: auf Beobachtungen und Messungen gegründet, welche vom 10ten Grade nördlicher bis zum 10ten Grade südlicher Breite, in den Jahren 1799, 1800, 1801, 1802 und 1803 angestellt worden sind*. Tübingen, Paris: Bey F.G. Cotta; Bey F. Schoell
17. Kirschner V et al (2023) ‘Measuring the relationships between various urban green spaces and local climate zones’, *Scientific Reports*, 13(1), p. 9799. Available at: https://doi.org/10.1038/s41598-023-36850-6
18. Konijnendijk CC (2023) ‘Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3-30-300 rule’, *Journal of Forestry Research*, 34(3), pp. 821–830. Available at: https://doi.org/10.1007/s11676-022-01523-z

19. Kreis D, Prominski M (2025) ‘Representing spatio-temporal relations between humans and non-humans: The role of landscape architecture in transdisciplinary research’, *GAIA - Ecological Perspectives for Science and Society*, 34, pp. 25–34. Available at: https://doi.org/10.14512/gaia.34.1.8
20. Kuttler W, Weber S (2023) ‘Characteristics and phenomena of the urban climate’, *Meteorologische Zeitschrift*, 32(1), pp. 15–47. Available at: https://doi.org/10.1127/metz/2023/1153
21. Larice M, Macdonald E (2007) The urban design reader. Routledge (The Routledge urban reader series), Abingdon
22. Latour B (2005) *Reassembling the social: an introduction to actor-network-theory*. Oxford New York: Oxford University Press (Clarendon lectures in management studies). Available at: https://doi.org/10.1093/oso/9780199256044.001.0001
23. Laue HM (2019) Klimagerechte Landschaftsarchitektur: Handbuch zum Umgang mit Elementen und Faktoren des Klimas im Freiraum. Patzer, Berlin Hannover
24. Lazarus RJ (2010) Super Wicked Problems and Climate Change: Restraining the Present to Liberate the Future. Georgetown University Law Center [Preprint]
25. Lenzholzer S (2015) Weather in the city: how design shapes the urban climate. nai010, Rotterdam
26. Look E-R (1985) *Geologie, Bergbau und Urgeschichte im Braunschweiger Land: (nördl. Harzvorland, Asse, Elm-Lappwald, Peine-Salzgitter, Allertal)*. Erw. und erg. Aufl. Schweizerbart (Geologisches Jahrbuch / A, 88)
27. Lovelock JE (2016) *Gaia: a new look at life on earth*. Second edition. Oxford, United Kingdom: Oxford University Press (Oxford landmark science)
28. Lovelock JE, Margulis L (1974) ‘Atmospheric homeostasis by and for the biosphere: the gaia hypothesis’, *Tellus*, 26(1–2), pp. 2–10. Available at: https://doi.org/10.1111/j.2153-3490.1974.tb01946.x
29. Ministery of Environment, Energy and Climate protection (2009) *Erfassung der für den Naturschutz wertvollen Bereiche in Niedersachsen 1984–2004 | Nds. Ministerium für Umwelt, Energie und Klimaschutz*. Hannover. Available at: https://www.umwelt.niedersachsen.de/startseite/service/umweltkarten/natur_amp_landschaft/weitere_fur_den_naturschutz_wertvolle_bereiche/biotopk biotope-in-niedersachsen-8871.html (Accessed: 27 April 2026)
30. Montero E, Van Wolvelaer J, Garzón A (2014) ‘The European Urban Atlas’, in I. Manakos and M. Braun (eds) *Land Use and Land Cover Mapping in Europe: Practices & Trends*. Dordrecht: Springer Netherlands, pp. 115–124. Available at: https://doi.org/10.1007/978-94-007-7969-3_8
31. Nature E (2019) *& Evolution* ‘Humboldt’s legacy’, 3(9), pp. 1265–1266. Available at: https://doi.org/10.1038/s41559-019-0980-5
32. Neuhaus A (2025) ‘Re-Representing Mattering Landscapes: Outlining a New Method and an Emerging Culture’. SocArXiv. Available at: https://doi.org/10.31235/osf.io/cpyq2_v2
33. Nohl W (1990) *Städtischer Freiraum und Reproduktion der Arbeitskraft: Einführung in eine arbeitnehmerorientierte Freiraumplanung*. 4. Aufl. München: IMU-Inst (Studien / IMU-Institut, 2)
34. Oke TR et al (2017) *Urban climates*. Cambridge: Cambridge University Press. Available at: https://doi.org/10.1017/9781139016476
35. Paez R (2018) Operative mapping: the use of maps as a design tool. Print edition, New York, NY: Actar Publishers
36. ‘PDF’ (no date)
37. Prominski M (2019) ‘Design Research as Non-Linear Interplay of Five Moments’, in M. Prominski and H. von Seggern (eds). London; New York : Routledge. Available at: https://doi.org/10.15488/19729
38. Rittel HWJ, Webber MM (1973) ‘Dilemmas in a general theory of planning’, *Policy Sciences*, 4(2), pp. 155–169. Available at: https://doi.org/10.1007/BF01405730
39. Salzgitter C (2021) Klimaschutzteilkonzept. Salzgitter City, Salzgitter
40. Salzgitter City (2026) *Labour market, Population, Environment*. Monthly report. Salzgitter City, Salzgitter
41. Scherer D et al (1999) ‘Improved concepts and methods in analysis and evaluation of the urban climate for optimizing urban planning processes’, *Atmospheric Environment*, 33(24), pp. 4185–4193. Available at: https://doi.org/10.1016/S1352-2310(99)00161-2
42. State Office for Statistics Lower Saxony (ed.) (2007) *Niedersachsen: Das Land und seine Regionen; Land, Regierungsbezirke, Landkreise, Kreisfreie Städte*. Hannover
43. Statistisches Bundesamt (2022) *Census 2022*, *Statistisches Bundesamt*. Available at: https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/Zensus2022/_publikationen.html (Accessed: 8 June 2026)
44. Stewart ID, Oke T (2012) ‘Local Climate Zones for Urban Temperature Studies’, *Bulletin of the American Meteorological Society*, 93, pp. 1879–1900. Available at: https://doi.org/10.1175/BAMS-D-11-00019.1
45. Mosimann T, Frey T, Peter Trute (1999) Schutzgut Klima/Luft in der Landschaftsplanung. Hildesheim
46. Verein Deutscher Ingenieure (2024) ‘Environmental meteorology - Climate and air pollution maps for cities and regions’. Verein Deutscher Inginierure. Available at: https://www.vdi.de/mitgliedschaft/vdi-richtlinien/details/vdi-3787-blatt-1-umweltmeteorologie-klima-und-lufthygienekarten-fuer-staedte-und-regionen (Accessed: 1 June 2026)
47. Verma D, Mumm O, Carlow VM (2022) ‘FoldingNet Autoencoder model to create a geospatial grouping of CityGML building dataset&#8217
48. Virtanen P et al (2020) ‘SciPy 1.0: fundamental algorithms for scientific computing in Python’, *Nature Methods*, 17(3), pp. 261–272. Available at: https://doi.org/10.1038/s41592-019-0686-2

Tables

Tables 1 to 3 are available in the Supplementary Files section.

Figures

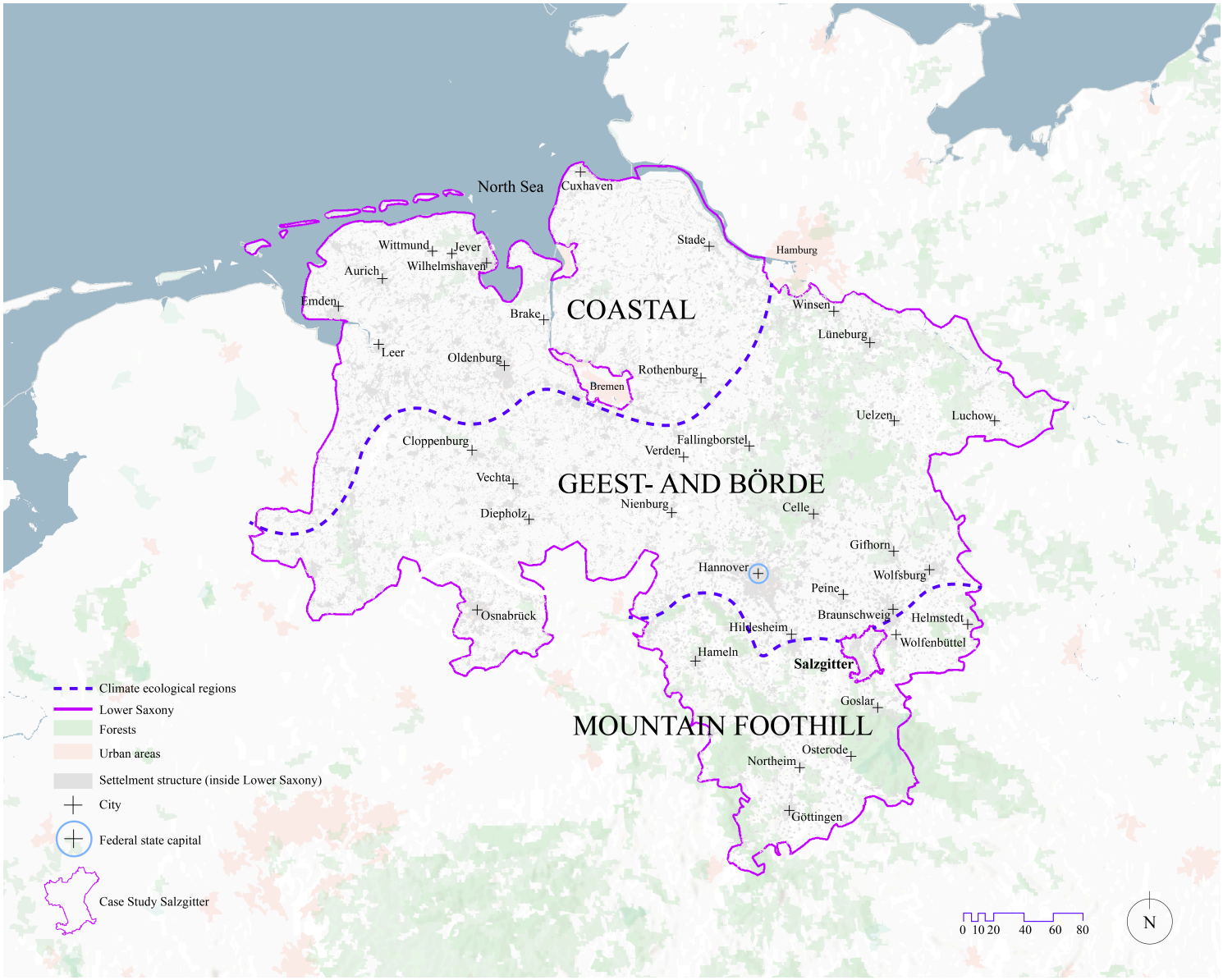

Figure 1

Climate ecological regions of Lower Saxony based on (Thomas Mosimann, Thorsten Frey, Peter Trute, 1999)
Caption: The three climate-ecological regions in Lower Saxony are large-scale areas with similar climatic conditions. As an overarching framework, they enable a reasonable transferability of a climate impact-driven typology of open spaces from an exemplary study area to the corresponding region, without neglecting site-specific context.

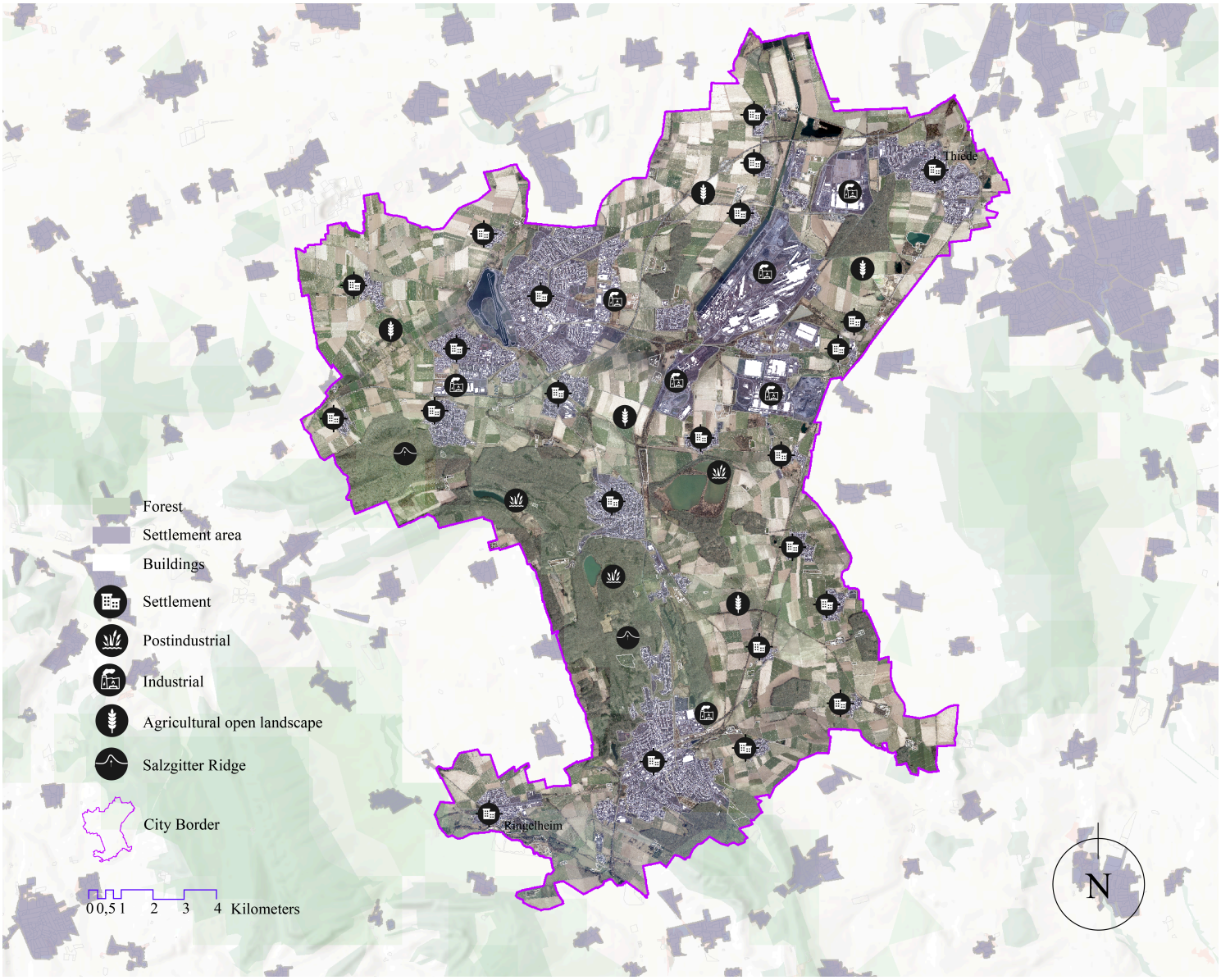

Figure 2

Case study Salzgitter – Aerial imagery provided by OpenGeoData Lower SaxonyCaption: The aerial imagery of Salzgitter gives a introductional overview of the case studies landscape. The located categories, Settlement, Postindustrial, Industrial, Agricultural, and Open landscape, and Salzgitter Ridge, highlight the diverse landscape structure.

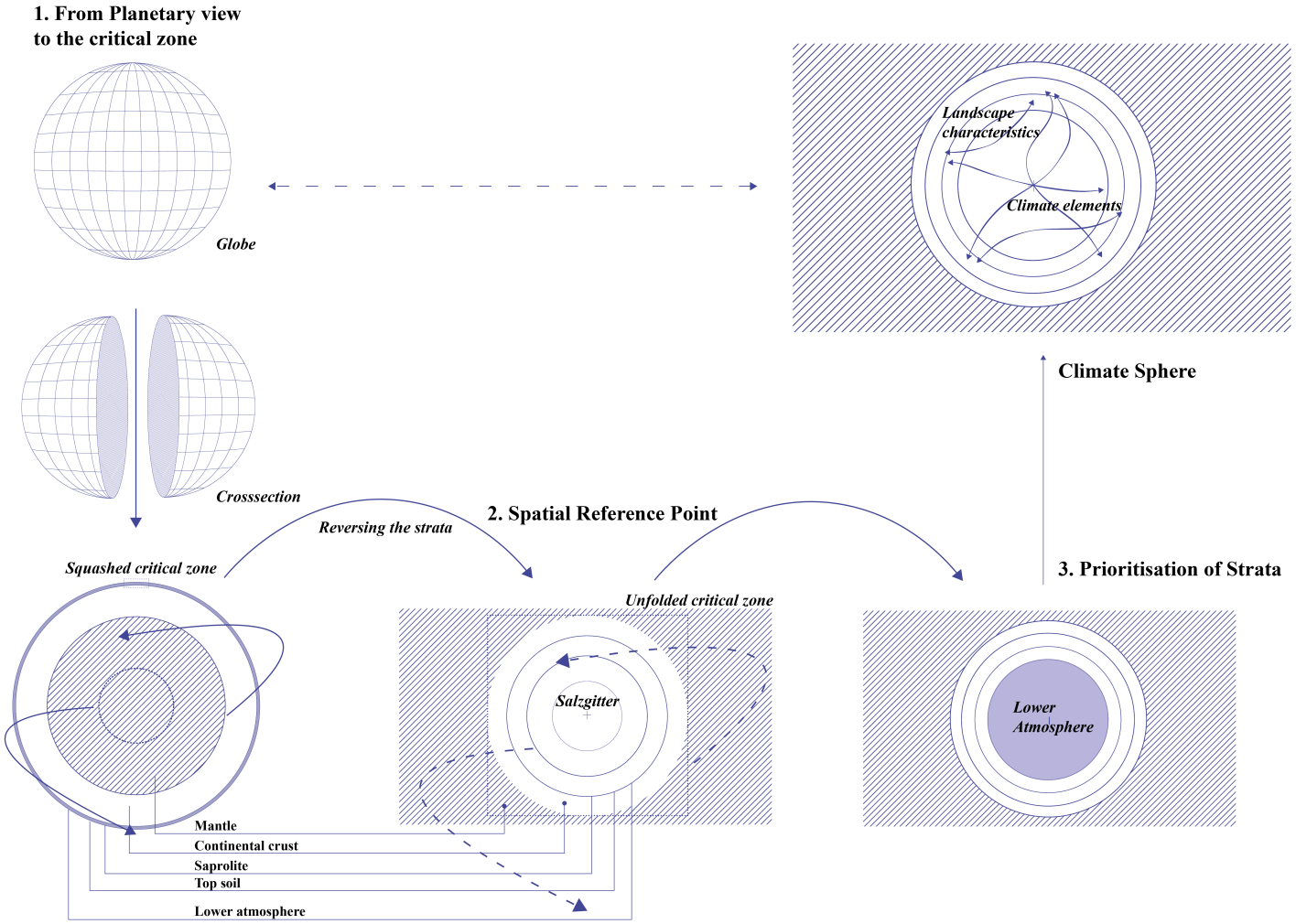

Figure 3

Climate Sphere Framework - (Aït-Touati *et al.*, 2022, p. 40)
Caption: With the Climate Sphere, we shift the projection system of a planetary view to the critical zone. By applying the methodological steps of the Gaiagraphy Soil Model, one of seven methods to visually engaging with the critical zone, the thin layer of life between saprolite and lower atmosphere becomes the center of the alternative projection system. This enables us to map the relationship between climate elements and climpact attributes of open spaces, a process that allows us to develop a sophisticated understanding of the climate impact of open spaces in our case study.

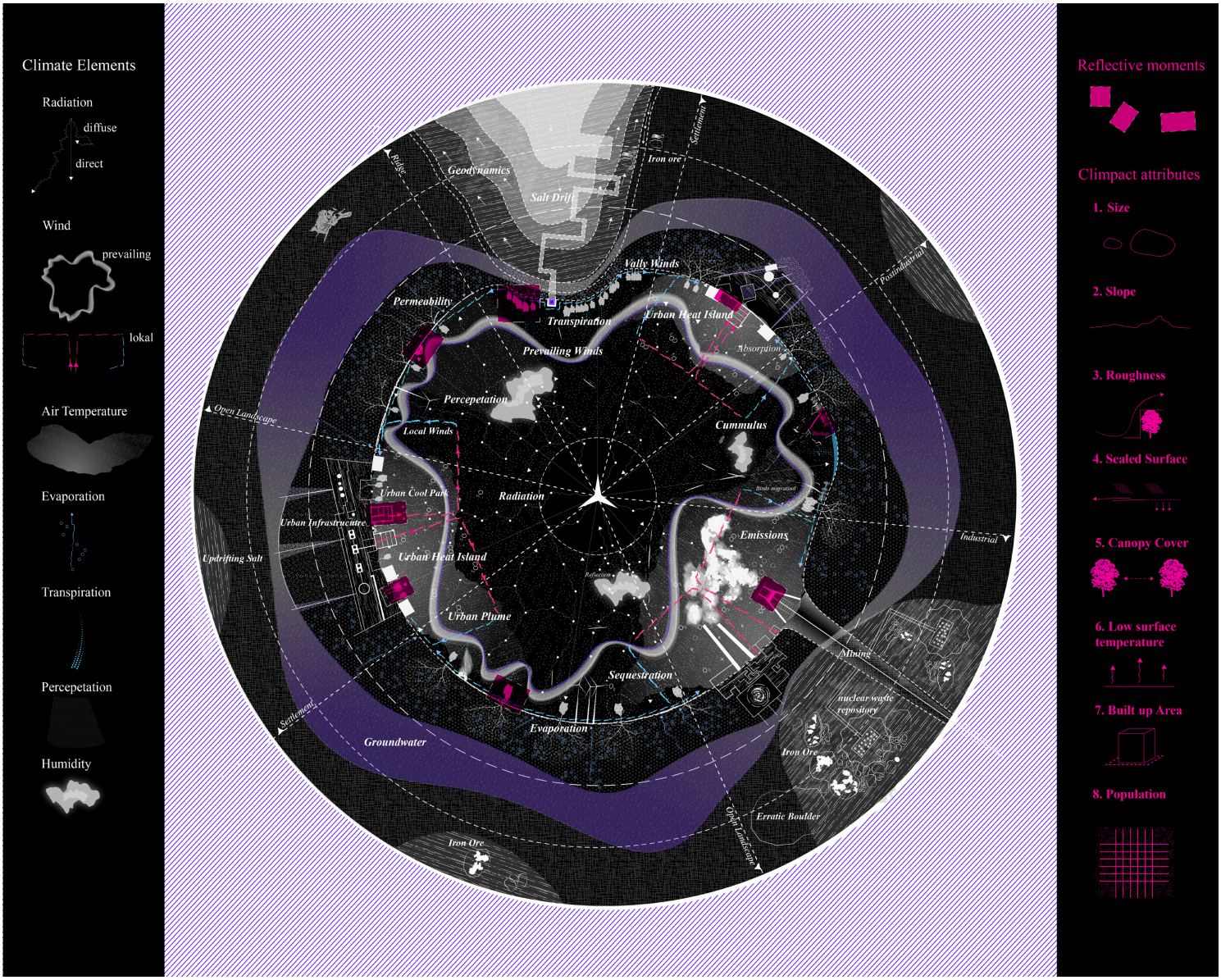

Figure 4

Climate Sphere Salzgitter

Caption: The Climate Sphere illustrates the complex interplay between climate elements (on the left) and the local, site-specific context of Salzgitter's landscape. The pink boxes highlight reflective moments from the case study analysis that led to the identification of a climate-impact attribute (on the right). The radiant structure enables us to demonstrate the systematic interlinkages between prevailing climatic conditions, landscapes, and the measurable units that must be assessed to quantify the climate impact of Salzgitter's open spaces.

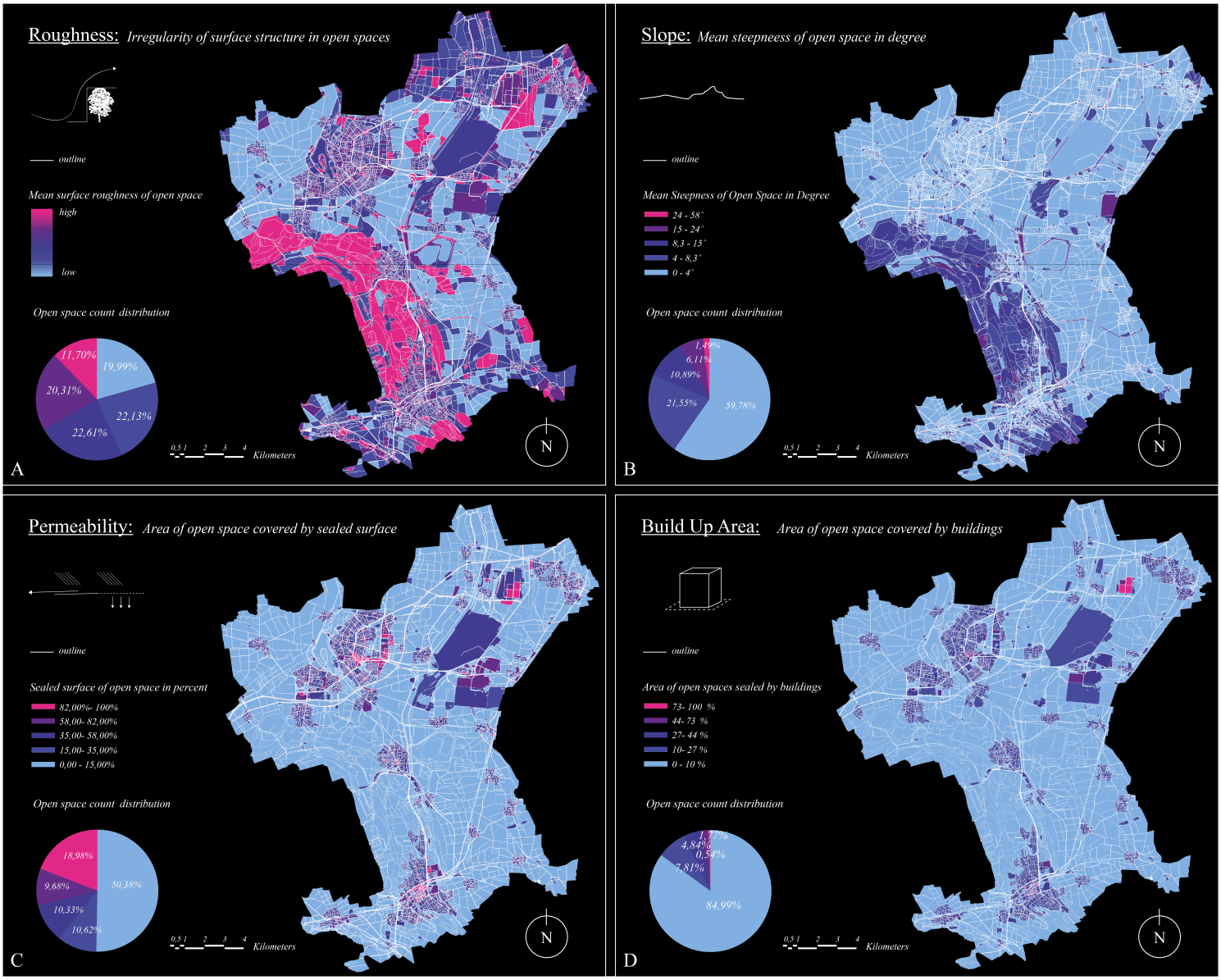

Figure 5

Cl*impact Attribute Performance* (A-D)

Caption: In Figures 5 and 6, every climate-impact attribute derived from the Climate Sphere is calculated for the 28,818 distinct polygons from the ALKIS dataset in Salzgitter. In addition to the performance of each attribute, the diagram in the bottom left shows the count of open spaces and their distribution across Salzgitter for each of the eight climate-impact attributes

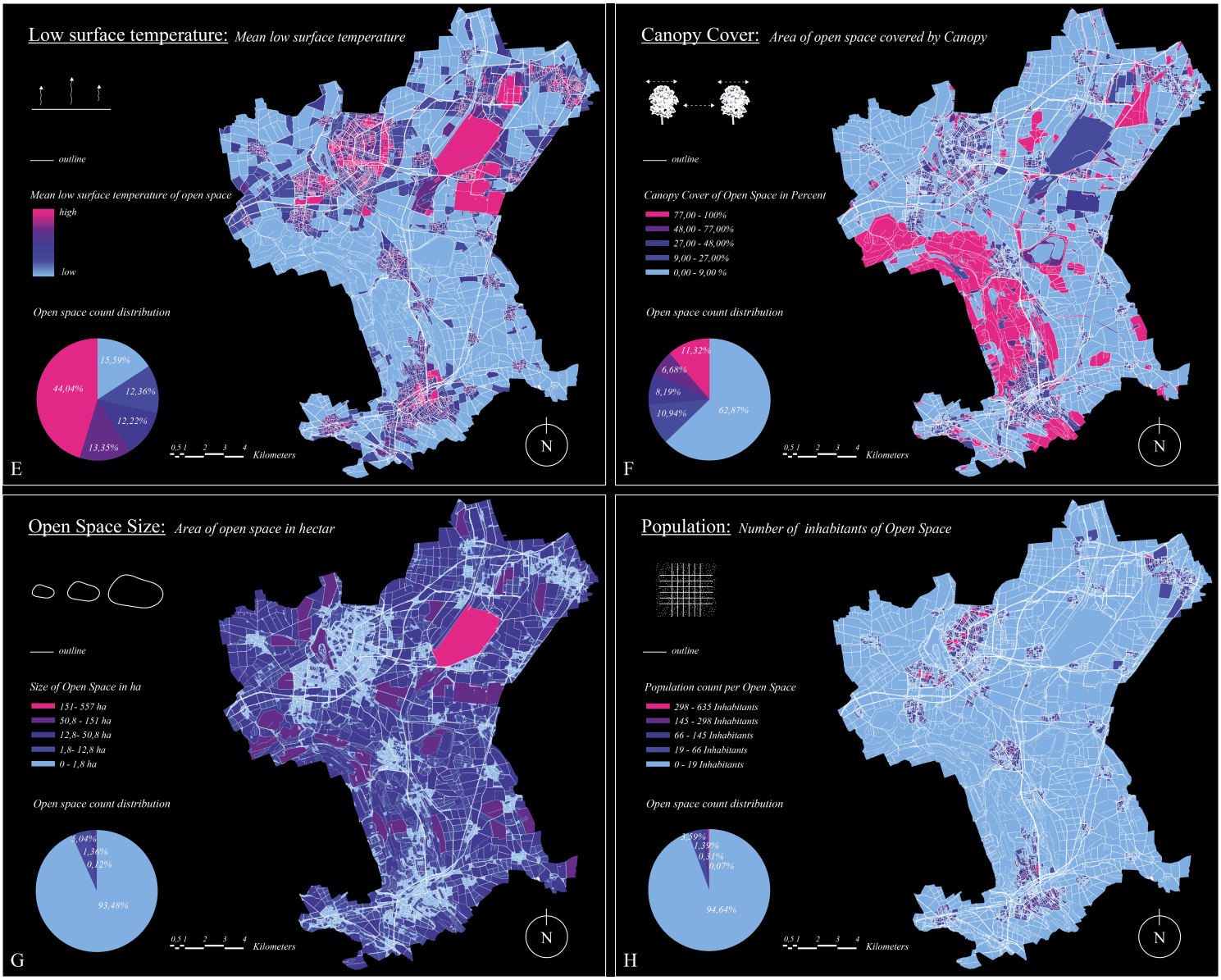

Figure 6

Climpact Attribute Performance (E-H)

Caption: In Figures 5 and 6, every climate-impact attribute derived from the Climate Sphere is calculated for the 28,818 distinct polygons from the ALKIS dataset in Salzgitter. In addition to the performance of each attribute, the diagram in the bottom left shows the count of open spaces and their distribution across Salzgitter for each of the eight Climpact attributes

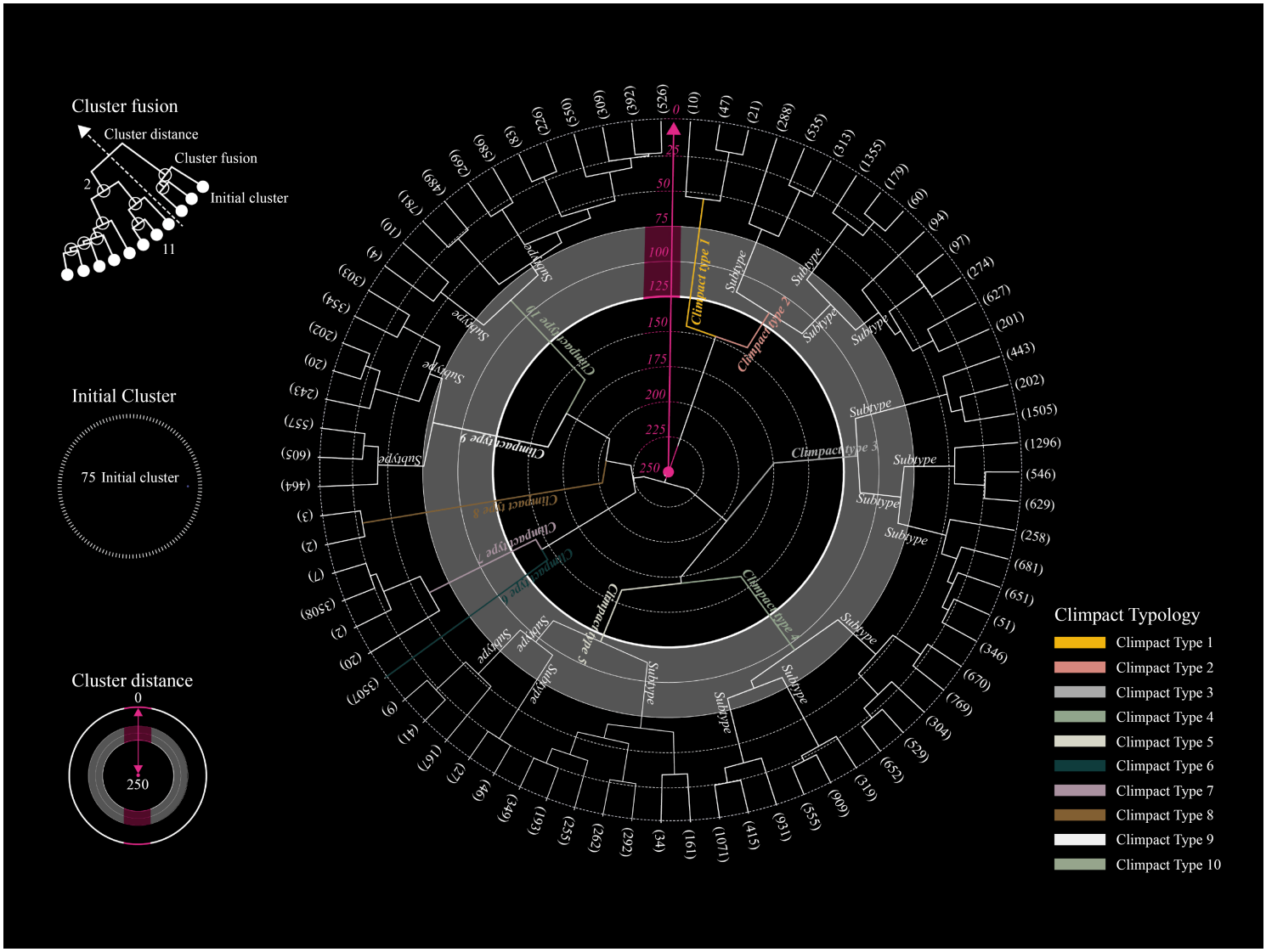

Figure 7

Radiant Cluster Dendogram

Caption: The hierarchical clustering resulted in 75 initial clusters of varying sizes. By tracing the paths along the cluster distance, it is possible to observe how clusters fuse depending on the distance threshold. At a cluster distance of 125, the Climpact typology yields 10 distinct open space classes, referred to as Climpact types. The subtypes at cluster distances of 100 and 75 examine the flexibility of the Climpact typology for spatial planning, as the number of open space categories and thus the level of differentiation can be adjusted

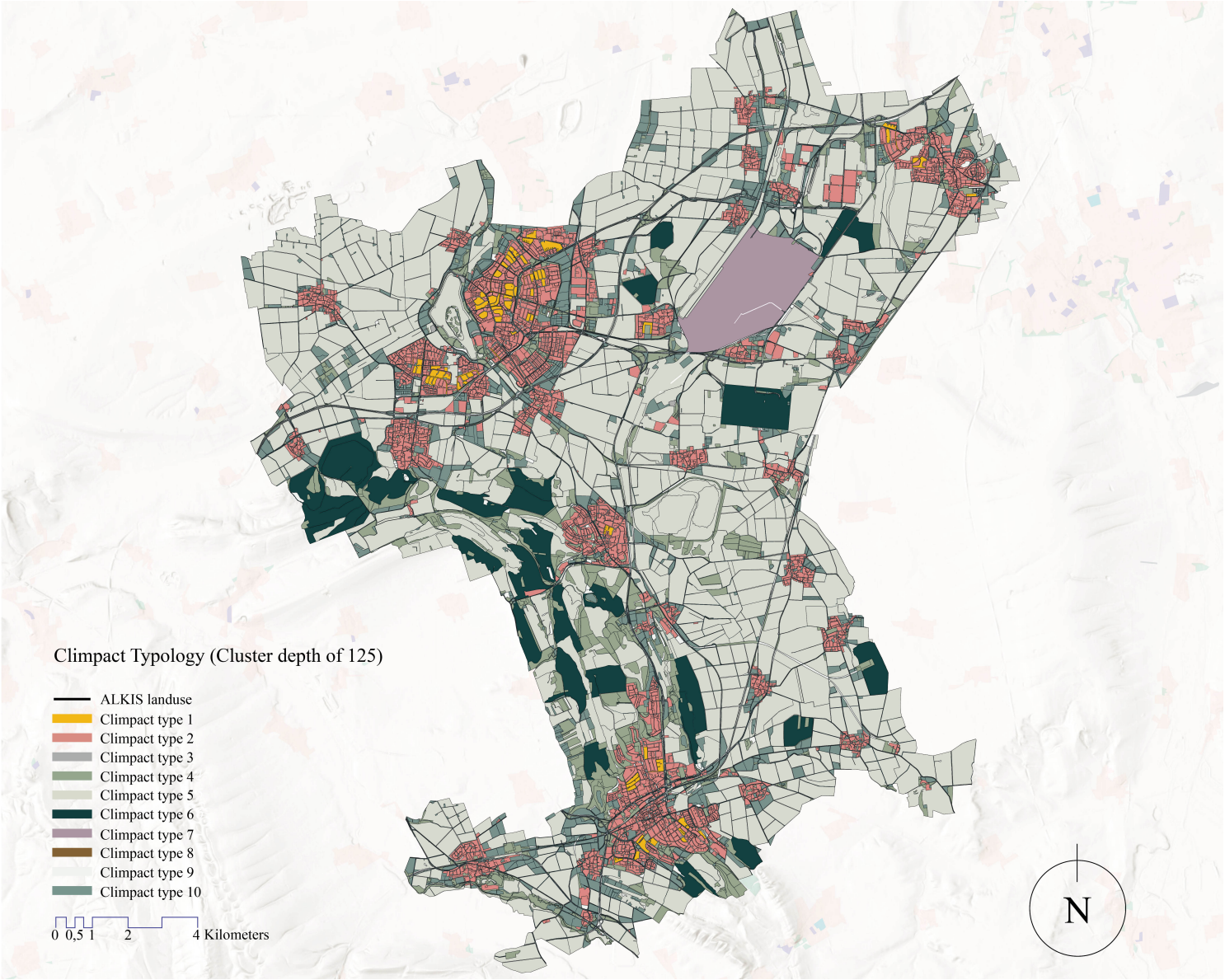

Figure 8

Climpact Typology at Cluster Distance 125
Caption: The 10 different Climpact types show the difference in Open space climate impact according to the Climpact attributes derived from the climate sphere.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- tables.docx