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LLM-BASED CONTENT ANALYSIS OF CLIMATE ADAPTATION STRATEGIES IN GERMAN REGIONAL PLANNING DOCUMENTS

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by

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ABSTRACT

This thesis evaluates the integration of climate mitigation and adaptation strategies within German regional planning documents using Large Language Model (LLM)-based content analysis. It investigates the standalone spatial distribution and temporal evolution of climate topics, as well as their correlation with socio-economic and environmental indicators. Findings reveal uneven emphasis: energy supply and flood protection show universal engagement driven by federal mandates, while more recent topics like carbon sinks and heat mitigation remain limited or geographically concentrated. Temporal analysis shows limited impact from legislative changes, given the long feedback and amendment cycle in Germany's top-down planning scheme. Spatially, urbanization correlates with heightened climate challenges but also increased capacity and awareness. The study recommends enhancing data infrastructure, mandating measurable local targets, and improving multi-level governance coordination to strengthen the effectiveness of spatial planning for climate resilience.

BIOGRAPHICAL SKETCH

Yucheng Zhang is an urban scientist who specializes in urban computational methods, including computer vision, natural language processing, and generative AI. Born and raised in Shenzhen, China - an emerging city known as an experimental ground of urban governance strategies and a hub for cutting-edge technologies, Yucheng is interested in exploring the potential of data-driven automated algorithms in understanding and improving cities. His research focuses on large-scale urban patterns, ranging from urban mobility, urban morphology, to subjective measurement of urban space, using big spatial datasets to capture the general image with minimized labor and time cost.

Yucheng holds a Bachelor of Science degree with honors from Cornell University in 2023 and is expected to receive a Master's in Regional Planning degree in May 2025. Following the completion of his Master's degree, he will join the Department of Urban Planning and Design at the Hong Kong University to pursue a PhD degree in Urban Analytics and Smart Cities.

To

my parents

in recognition of their love

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LIST OF ABBREVIATIONS

BBSR	Bundesinstitut für Bau-, Stadt- und Raumforschung (Federal Institute for Research on Building, Urban Affairs and Spatial Development)
BNatSchG	Bundesnaturschutzgesetz (Federal Nature Conservation Act)
BRPH	Bundesraumordnungsplan Hochwasserschutz (Federal Spatial Planning Act for Flood Protection)
CCRA	UK Climate Change Risk Assessment
DSS	Decision Support Systems
DWD	Deutscher Wetterdienst (German Weather Service)
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act)
GDP	Gross Domestic Product
INKAR	Indikatoren und Karten zur Raumentwicklung (Indicators and Maps for Spatial and Urban Development)
KAnG	Klimaanpassungsgesetz (Climate Adaptation Act)
LEP	Landesentwicklungsplan (State Development Plan)
LLM	Large Language Model
MKRO/RMK	Ministerkonferenz für Raumordnung / Raumentwicklungsministerkonferenz (Ministerial Conference for Spatial Planning)
MORO	Modellvorhaben der Raumordnung (Demonstration Projects of Spatial Planning)
NEP	Netzentwicklungsplan (Network Development Plan)
PV	Photovoltaic
ROG	Raumordnungsgesetz (Spatial Planning Act)
ROPLAMO	Raumordnungsplan-Monitor (Spatial Planning Monitoring System)
RPV OEOE	Regionaler Planungsverband Oberes Elbtal/Osterzgebirge (Regional Planning Association Upper Elbe Valley/Eastern Ore Mountains)
SDI	Spatial Data Infrastructures

UHI	Urban Heat Island
WindBG	Windenergieflä

Chapter 1. Introduction

Situation Overview

The impact of climate change is becoming more significant at the global level. Consequential events from global warming, including more intense hurricanes, storm surges, and droughts, have been observed considerably more frequently since 2000 than over the last century (U.S. Global Change Research Program, 2009). Though it is hard, and extremely limited to quantify the negative impacts of the changing global climate on the economy and social welfare, an estimation of the economic impact can put into context how climate change has trapped people in poverty and affects the growth of the global economy. Researchers estimated that for individuals, through unprecedented climate problems, including the increasing cost of cooling and heating, decreased crop yields, the spreading of infectious diseases, an increase of 2.5°C of the global mean temperature would diminish the welfare of someone as if they lost 1.3% of their income (Porter et al., 2014; Tol, 2018). In the context of this thesis's study area - Germany, in 2024 alone, storm surges, flooding, and other natural disasters have caused an economic loss of over 5.5 million Euros (Dosch, 2025).

In recent years, the increasing awareness of climate challenges has intensified the conflicts with increasing land-use pressures. As effective climate adaptation inherently demands cooperation across multiple governance layers due to its cross-boundary nature, efforts of climate adaptation in spatial planning and development often start with overarching thematic strategies at the high-level administrative entities like the European Union. Through these cross-sectional and cross-stakeholder efforts, the EU strategies, laws, and programs set tangible, comprehensive, and often legally binding goals and frameworks for the member states. Not only does it serve as an important foundation for sustainable European development, but these overarching guidelines also ensure both the administrative and economic cooperation and coordination among the smaller entities.

For example, on the topic of greenhouse gas emissions, the European Green Deal 2019 established an overarching goal for zero net emission of greenhouse gases by 2050 (Fetting, 2020). A subsequent legally binding version of the Green Deal, the European Climate Law, specifies the short-term goal of achieving a 55% greenhouse gas reduction by 2030 compared to 1990 levels (European Climate Law, 2021). Similarly, with regard of habitat protection and restoration, the Nature Restoration Law regulates that member states should develop national restoration plans, with a goal of covering 20% of land and sea area by 2030 and all ecosystems in need of restoration by 2050 (Nature Restoration Law, 2024). These legally binding requirements ensure the efficiency of enactment in the multilateral administration system.

The top-down coordination from the European Union aims to assist a collaborative approach in addressing the spill-over effects of climate change, that actions (or more often, inactions) in one area have consequences beyond regional jurisdiction. Policy documents, like the Territorial Agenda 2030 supports a more uniform establishment of spatial planning policy in EU by promoting spatial cohesion across its member states (Ministers responsible for Spatial Planning and Territorial Development, 2020). Climate mitigation inherently requires significant resource input for coordination and implementation across different levels of government and sectors, including more non-conventional processes like lengthy planning and approval stages, extensive stakeholder consultations, and the continuous alignment of regional plans with evolving federal guidelines. Other cohesion policies, in recognition of these difficulties, finance spatial and regional development measures to reduce the fiscal costs and administrative efforts required. The publication on Cohesion policy in 2021-2027 designates that European Regional Development Funds (*Europäische Fonds für regionale Entwicklung*, EFRE), provides funds for spatial and regional development in the context of interregional coastal and sea basin protection (European Commission, 2020).

Spatial planning, regulated by these overarching guidelines and objectives, faces increasing pressures from competing land-use interests by the heightened urgency for climate adaptation and mitigation measures (Dosch, 2025). These pressures, though with different priorities across geographical regions, converges in similar programs of securing sufficient land for renewable energy projects, enhancing flood prevention and water resource management, and maintaining ecological corridors for biodiversity conservation and carbon sequestration. Urban planners, as both mediators and supervisors, recognize regional plans as the critical instrument for translating national and international climate mitigation and adaptation strategies into legally binding and actionable frameworks.

Rising demands on spatial planning

In 2016, the Ministerial Conference for Spatial Planning in Germany (*Ministerkonferenz für Raumordnung*, MKRO) positioned spatial planning by federal and state governments as a central framework for climate adaptation, mitigation, and the transition to renewable energy (Dosch, 2023; MKRO, 2016). Since the implementation of the 2016 guiding principles and prior solutions, extensive measures have been taken, in spatial planning documents, to cooperate with the EU level and national level goals. For example, National Flood Protection Program (NHWSP) and the Federal Government's National Water Strategy (BMUV 2023c) impose new requirements on land use planning to secure retention areas and manage water resources. It also references the *Aktionsprogramm Natürlicher Klimaschutz* (Action Program for Natural Climate Protection, BMUV 2023a) which promotes measures like peatland rewetting as part of climate mitigation. These initiatives contribute to a tighter policy "target frame" for planners to incorporate climate adaptation and mitigation goals.

Such federal strategies have created increased demands on spatial planning, that planning must now accommodate renewable energy expansion targets (in response to the EU Green Deal for reduced GHG emission goals), stricter flood risk management requirements (Also from EU), as well as other climate adaptation/mitigation goals. Spatial planning documents are thus called upon to fulfill local government's coordination role to a greater extent, aligning sectoral needs, climate goals, and regional development with one another. As a mediator between different interest and levels of governances, local planning authorities are not acting in isolation but within a multi-level governance framework of strategies, laws, funding, and knowledge transfer.

Problem Statement

However, although the concept of regional planning and climate adaptation each has individual *profunden Kenntnisstand* ("Profound Knowledge") in their own scheme, there has been a lack of integration for effective implementation (Gruehn et al., 2010). According to several pilot studies on existing spatial plans in Germany since 2014, climate adaptation strategies until then had so far only made limited inroads into regional planning practices and were rarely cited as a justification for specific planning actions (Schmitt, 2016; Zaspel-Heisters & Benz, 2020).

Even though climate and energy-related concerns have been bolstered by legal changes, like the Federal Climate Protection Act (KSG) and the Renewable Energy Sources Act (EEG), spatial planning still requires further empowerment. Currently, the spatial plans are more in coordination only with the existing legal requirements instead of the fast-changing climate challenges. Pre-studies, expert interviews, and practical workshops have found that the current lack of more flexible planning instruments, innovative approaches, and cooperation between different planning levels leads to substandard actions in meeting the climate challenges ahead (Dosch, 2025).

Similarly, even for more prominent fields of actions, like mountain range protection, which already had long-term exposure to the administrative entities and the public, also showed regional disparities in laying out clear action plans and securing implementation through legally binding processes (Schmitt, 2016). Implementation status as of 2014 demonstrated a neglect regarding the negative externalities diffused from Alpine and other mountain regions to lower altitude areas by limiting mountain protection strategies in regional spatial plans only to high alpine regions, only in coordination with pre-existing laws like the *Federal Forest Act* (Bundeswaldgesetzes, BWaldG). These potential risks include compromised water supply and flood retention capacity, diminished carbon sequestration capacity in the broader regions, and reduced biodiversity and natural habitats (Emelko et al., 2011; Schmeller et al., 2022; Turkelboom et al., 2021).

The aforementioned mismatches between the written strategies and real-world challenges urged planning authorities to conduct rounds of supervision, coordination, and revision on the existing planning framework and their resulting spatial planning documents. Scholars have well acknowledged that plans are historically “failing to live up to their promise of being rational, comprehensive, and implementable”, a clear indication of such mismatches (Lyles & Stevens, 2014). Plan evaluation is thus considered the basis for improvement, as the process of identifying specific strengths and weakness om the plans logically provides the incentive for planning authorities to engage in the improvement circle (Berke & Godschalk, 2009).

However, such systematic evaluation of these planning documents presents significant time and resource challenges given their volume and structural complexity. Germany’s spatial planning structure encompasses 16 states and 116 planning regions, resulting in over 900 comprehensive/partial updates of planning documents, spanning more than three decades. Traditional manual analysis of these documents requires extensive time and specialized expertise, making comprehensive and timely assessment processes difficult. For instance, a thorough review of a typical single spatial plan of around one hundred pages would take a competent planner with familiarity with the technical contents at least 10 hours to read through (Fu et al., 2022; Lyles & Stevens, 2014). For a complete review of all German regional plans, this adds up to approximately 9000 hours, or 1125 working days of highly specialized labor. Admittedly, researchers have explored computational approaches to speed up the process, using keyword-based text mining techniques to quantify the incorporation of climate adaptation strategies. However, limitations exist in these techniques, as traditional computational methods can produce false positives by identifying climate-related terms without considering their contextual significance, or miss important thematic elements expressed through varied, yet not captured by the pre-defined keyword list.

These practical and analytical challenge hinders the evaluation of how effectively regional plans incorporate climate strategies and how they vary across geographical regions, as sought in previous studies. Thus, to avoid the ever-widening gap between climate policy objectives and their practical implementation in spatial planning, this thesis explores a novel methodological framework using Large Language Models (LLMs) for systematic, context-aware analysis of planning documents, with the goal of achieving more time- and cost-efficient and accurate assessment of climate-related topics across Germany.

Aim, Scope, Audiences, and Proposed Contribution

The research focuses on identifying spatial and temporal patterns in climate-related planning priorities, and investigating correlations between planning emphasis and real-world demographic, economic, and geographic indicators. This thesis is situated in the context of the 2016 MKRO guiding principle and prior resolutions (2013 and 2016) on climate adaptation and energy transition that established important bases for climate-responsive spatial development. Based on the MKRO defined fields of climate actions, 208 planning documents since 1990 to 2023 were assessed. Rather than focusing on implementation outcomes, this research specifically examines the thematic emphasis within planning documents as an indicator of policy priorities and planning intentions across German Regions. The findings provide insights into the extent to which climate-related topics are integrated into federal-level, top-down regional planning schemes, socio-economic localized advantages, and geographic characteristics.

The spatial analysis reveals the following notable trends: Energy Supply and Flood Protection exhibit uniform and stronger attention across all regions, reflecting strong, centralized federal policy mandates on regional plans rather than region-specific factors. Heat mitigation, Heavy Rain, and Water shortages correlate positively with urbanization and economic development. These densely populated, economically advanced regions face greater environmental pressures but also possess the resources and public support to incorporate climate adaptation strategies. Similar advantages in urban areas also contribute to the prominence of technology-and-resource-dependent topics, such as carbon sink strategies. Geographic exclusivity influences climate prioritizations, as seen in the strong association between mountain protection and alpine regions, and between coastal protection and northern coastal zones. However, some geographically relevant topics are unevenly distributed, suggesting a potential lack of recognition of climate risks. Similarly, Tourism-related Climate Strategies align with regional tourism industries and geographical advantages, particularly in coastal and mountainous areas.

The temporal analysis reveals that the number of planning documents and climate topics in the documents remained relatively stable over time from 1995 to 2025, despite the enactment of major federal climate policies. This trend can be attributed to the slow update cycle of regional planning frameworks, where full revisions occur infrequently. Additionally, regional plans often evolve through incremental amendments, reflecting ongoing legislative updates rather than sudden changes of focus. This suggests that while federal mandates and the awareness of climate mitigation influence climate planning, their impact is gradual and cumulative rather than immediate.

There are also complex relationships between political affiliations and climate planning priorities. AfD, despite its national climate skepticism, shows a strong positive correlation in areas like flood protection, likely due to its support in flood-prone rural areas. Conversely, parties traditionally supporting strong climate action, such as SPD and the Greens, do not exhibit consistent positive correlations with planning topics. However, limitations such as a small sample size at the regional level, and reliance on 2021 electoral data introduce uncertainty. Additionally, the aforementioned national mandates on energy supply and flood protection, as well as geographical characteristics, may override regional political influences.

With the aforementioned results, this research serves multiple audiences across academic and governmental domains. For planning scholars, this thesis contributes to the topic of the effectiveness of spatial planning instruments in addressing climate challenges by providing empirical evidence. Climate adaptation researchers will find value in the systematic assessment of how climate strategies are represented across diverse regional contexts. It also extends on the ongoing discussions on the analytical toolkits for examining planning document content. Computational analysts would benefit from the application of LLMs to policy document analysis, as well as the discussion on upstream infrastructures like all-in-one management and sharing systems for planning documents, which all fall under the emerging area with significant potential for interdisciplinary knowledge transfer and analysis.

For governmental and planning practitioners, particularly the Federal Institute for Research on Building, Urban Affairs and Spatial Development (*Bundesinstitut für Bau-, Stadt- und Raumforschung*, BBSR) as a direct partner in this research, this thesis provides practical insights into the current regional variations in climate adaptation planning across Germany. The methodological framework, in comparison with their previous pilot studies, offers them a resource-efficient yet more statistically justifiable approach to evaluate document contents. The results of this study enable them to identify potential gaps in climate policy integration and possible correlations with specific regional characteristics. Regional planning bodies can also utilize the findings to benchmark their implementation of climate strategies with comparable regions and identify potential areas for improvement. From the technical aspect, especially under the current hype of finding values of computational AI tools like LLM for governance applications, this domain-specific application of language models serves as an experimental sample for streamlining the evaluation process while addressing unique challenges in planning document evaluation.

Structure

This thesis is structured in six chapters. The introductory chapter provides a high-level overview of the research context, highlighting the motivation and contribution of the study, as the need for a more effective evaluation instrument in response to climate change has emerged.

Chapter 2, the literature review chapter, establishes the contextual, theoretical, and methodological framework for the research through a comprehensive review of three intersecting domains. This chapter first explores the hierarchical structure of German spatial planning systems and documents, providing essential context for understanding the institutional framework within which the planning, implementation, and evaluation loop occurs. Second, it examines Germany's current climate issues and climate planning strategies, providing clear definitions of climate adaptation, climate mitigation, and energy transition strategies, as well as their expected outcomes. Third, the chapter reviews existing applications of Natural Language Processing in planning documents, identifying the advancements and limitations compared to traditional NLP methods. An introduction to Large Language Model is also included, as this thesis has a designed audience of urban planning practitioners who are less familiar with technical details.

Chapter 3 presents the research design, data collection, and analytical frameworks of the study. The chapter begins with a description of the corpus of 208 regional planning documents and the preprocessing techniques. The collection and analysis of the real-world indicators - demographic, economic, geographical, and political variables - are subsequently presented. The complete analysis pipeline is then presented, together with the justifications for model selection, fine-tuning, and the validation strategy.

Chapter 4 provides a comprehensive analysis of the results. The chapter examines the internal and external correlations between regional characteristics and planning emphasis. Visualizations, including correlation matrix and density maps, are presented to reveal the distinctive patterns of regional prioritization, including the universal emphasis on energy supply and flood protection across regions, the urban concentration of heat mitigation strategies, and the geographic exclusivity of coastal and mountain protection.

The final Chapter summarizes key findings into implications for both planning practice and methodological advancements. Policy recommendations, specifically under the context of the German planning scheme, as well as generally applicable suggestions, are offered. The chapter also evaluates the advantages, biases, and limitations of the proposed LLM method based on the misalignment with empirical studies and local knowledge from practitioners. Research limitations are acknowledged, and promising directions for future research are also presented.

Chapter 2. Literature Review

Planning Structure in Germany

Germany's planning system is organized as a multi-level hierarchy, with distinct roles at the federal *(Bundesrepublik Deutschland, Bund*), state or government regions (*Bundesländer/Länder; Regierungsbezirke*), and local authorities like Districts (*Kreise*) and Municipalities (*Kommunen/Städte and Gemeinden*). Compared to unitary states, spatial planning in Germany is characterized by the shared responsibility distributed across the above administrative levels. This multi-tiered structure, while arguably offering subsidiarity and flexibility with regard to the nuanced political and regional diversity, inevitably introduces complexity and administrative costs.

At the federal level, the *Bund* defines overarching goals and framework for spatial planning through the Federal Spatial Planning Act (*Raumordnungsgesetz*, ROG) and the Federal Building Code (*Baugesetzbuch* - BauGB) (Danielzyk & Münter, 2018; ROG, 2008). Key federal institutions involved are the Federal Ministry for Housing, Urban Development and Building (BMWSB) and its departmental research agency, the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), which conducts research, monitors spatial trends, and supports policy development (*Organisation Chart*, 2025; *The Federal Institute*, n.d.). Federal's influence is thus primarily exerted through the two legislative frameworks mentioned above, as well as non-binding national guiding principles in sectoral planning (for example, transportation infrastructure networks and renewable energy grids) and corresponding funding to support these spatially relevant plans (VASAB CSPD/BSR, 2023). Currently, federal focus has been emphasized on sustainable spatial development given the emerging climate challenges, striving to balance between social and economic development demands on lands with their ecological function.

While the above *Bund* level planning lays out the objectives and guiding principles for spatial planning, the 2006 German federal reform revoked the legally binding nature of ROG on lower-division planning. Since then, the largely decentralized structure allows the 16 states to deviate from the federal framework and be responsible for the spatial planning within their own territories. Nevertheless, the most important function of federal level planning is its statutory principles that are weighed heavily at the lower stream of the planning scheme, where, even given such flexible leeway, only two of the states, Bavaria and Lower Saxony chose to exercise this right (Münter & Reimer, 2023). Bavaria has implemented its own Land Use Planning Law (*Landesplanungsgesetz*), emphasizing the concept of "spatial justice" defined as equal access to basic services for all people (Dudek et al., 2024). Lower Saxony updated its spatial planning program (*Landes-Raumordnungsprogramm*, LROP) in 2017, in alignment with the national level guideline of renewable energy development, which designates priority areas for wind energy farms (Marine Spatial Planning Global, 2025). This reflects the planning scheme in Germany that the Federal Spatial Planning Act's legal certainty remains high, as individual state derogations still serve for the outlined goals (Zaspel-Heisters & Haury, 2016).

As mentioned above, at the regional level, the planning regions (*Planungsregionen/planungsraum*) are the main entities that prepare regional plans that translate state-level objectives into more detailed land-use designations. While the states holds primary responsibility for the implementation of federal laws and significant administrative power, planning regions serves as an intermediate level, situated below the often abstract, state-wide strategic and above detailed land-use-based local planning (Axel Priebs, 2018). Planning Regions are geographically defined sub-areas of the state land, specifically for the purpose of regional planning within spatial districts with shared geographical or economic characteristics. The establishment of these regions that cross municipal boundaries aims to foster the coordinated spatial development within areas with functional and economic interdependencies, given their comparative advantage in certain sectors.

Finally, the local level agencies - municipalities (*Gemeinden* and *Städte*) exercise their constitutionally guaranteed right of self-government, which, in the planning context, the local planning autonomy, that is legally supported by the Federal Building Code (*Baugesetzbuch*, BauGB). Municipalities are responsible for land-use planning through two instruments: the preparatory land-use (*Flächennutzungsplan* - FNP) plan that defines the intended use for the entire municipal territory, and legally binding land-use plans (*Bebauungspläne* - B-Plan), which set forth specific, legally enforceable regulations for particular development areas (VASAB CSPD/BSR, 2023). It's only through these supra-sectoral, spatial planning acts at the local level that the "superordinate", federal/state-level acts with a focus on coordinating diverse geographical and sectoral planning can be made legally binding on individual subjects within the jurisdiction of the smaller planning parcels (Zaspel-Heisters & Haury, 2016).

However, at the sub-state level, the structure and operation of spatial planning in Germany have notable differences between the three city-states (*Stadtstaaten*) - Berlin, Bremen, and Hamburg - and the other 13 larger area states (*Flächenstaaten*). The city-states operate as unique administrative entities with consolidated functions of both federal states and municipalities (Paris & Gustedt, 2022). In these city-states, the three levels of planning (state, regional, and municipal) are typically merged or operate with close integration, resulting in the fact that their state-level spatial development plans (or their equivalent) often directly function as the municipal level plans (FNP). Consequently, city-states are not required to establish separate regional plans for sub-state areas per the Federal Spatial Planning Act (ROG), as they do not have a clearly delineated spatial hierarchy of state, regional, and municipal planning levels (Axel Priebs, 2018; ROG, 2008).

This structural difference can lead to potential disparities in policy implementation. The elimination of the additional regional planning tier could allow for a more direct and swift translation from state-level policies (which, are often more influenced by federal objectives, including climate strategies, into binding land-use plans). On the other hand, the closely-knit relationship across different planning agencies in city-states is associated with a unique set of challenges, including high population density and intense competition over land. These factors can cancel out the increased efficiency in decision-making and implementation of climate measures from the shortened path from policy formulation to local implementation.

Given the introduced multi-tiered spatial planning scheme, this study specifically focuses on analyzing planning documents at the sub-state, planning region level. These corpora are strategically chosen as regional plans operate at a scale sufficiently detailed to reflect local geographic, socio-economic, and ecological nuances while being adequately general to carry out inter-regional comparative analysis. Federal-level plans, by their nature, set broad strategic objectives and legislative frameworks, and thus lack the regional specificity and diversity required for an comparison on localized climate planning actions. In contrast, local-level plans tend to concentrate heavily on specific land-use criteria and parcel-level details, thus limiting their scope and suitability for the regional comparison.

Therefore, we believe that regional plans serve as an optimal analytical unit for this study, which effectively reflects the spatially diverse and context-specific efforts of climate-related strategies across different planning regions in Germany.

German Climate Planning Strategies

The Climate planning strategies in Germany followed the top-down planning scheme, with detailed regulations and goals posted at the national level. The country's climate planning has evolved substantially since the 1980s, stimulated by the early environmental awareness and the subsequent comprehensive national strategies that focus on both climate mitigation (emissions reduction) and adaptation (water/heat management, habitat protection, etc.) strategies (Cavender & Jäger, 1993). In 1986, the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (*Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit*, BMU) was established, a significant step in the history that significantly strengthened the administrative capacity and legal weight of environmental policies (Watanabe & Mez, 2004). By the 1980s, through both comprehensive reports like "*Schutz der Erde"* (Protecting the Earth) and other public readers like the magazine *Der Spiegel*, the German government and public had built a consensus on the urgency and necessity of climate actions (*A (Very) Brief Timeline of Germany's Energiewende*, 2017; Watanabe & Mez, 2004). In 1990, the Federal Cabinet set a CO2 reduction target to cut emissions by 30% by 2005 compared to 1987 levels through focused efforts on renewable energies. This ambitious goal, as well as the high level of agreement achieved within the legislative commission, signaled Germany's early commitment to climate mitigation and provided a solid foundation for future climate policies throughout the 1990s (Bang, 2002).

Early policy efforts in the 1990s continued to focus primarily on energy efficiency improvement and the promotion of renewable energy sources, influenced by various legislative acts, domestic politics, and international commitments. The 1991 Electricity Feed-in Act obliged utility companies to purchase electricity generated from renewable sources at subsidized rates, providing significant economic incentive for the transition to wind and solar power (Karapin, 2012). What else contributed, though largely unintended, is the reunification of Germany in 1990. The economic restructuring and deindustrialization in the former East German states led to sharp declines in both energy consumption and emissions. With the closure of old lignite plants in East Germany and the spurring wind farms, the country played a notable role in international climate agreements, contributing to a 21% emission reduction under the Kyoto Protocol's first commitment period from 2008 to 2012 (Watanabe & Mez, 2004). These achievements and continued commitments in climate mitigation show the effectiveness of federal-level climate adaptation strategies, which are often effectively translated into action plans in lower-level planning documents.

The central pillar of Germany's modern mitigation strategy is the Renewable Energy Source Act (*Erneuerbare-Energien-Gesetz* - EEG) enacted in 2000. It replaced the 1991 Feed-in Act by imposing a nationwide feed-in tariff system for electricity generated from renewable sources (Karapin, 2012). This policy ensured long-term investment security for renewable energy farms (mostly wind farms, but also solar, biomass, hydro, and geothermal) and thus resulted in a significant rise in the shares of renewable sources - from 6% in 2000 to about 28% by 2014 (World Future Council, 2015). In alignment with the decreasing technology costs and increasing market-based support mechanisms in spatial planning, the EEG has been amended numerous times (e.g., 2004, 2008, 2012, 2014, 2017, 2021, 2023) - which was well-reflected in the planning documents as partial updates on wind power. For example, the 2023 amendment adjusted the goal of renewable energy share to 80% in gross electricity consumption by 2030 (Erbach, 2024).

While mitigation efforts dominated early climate policy, the recognition that some climate change impacts were unavoidable led to the development of a formal national framework for adaptation. The German Strategy for Adaptation to Climate Change (*Deutsche Anpassungsstrategie*, DAS) was adopted in 2008, the first comprehensive federal-level framework for climate actions across 15 sectors, including water management, forestry, energy, and tourism. The goal of DAS was to provide guidance for stakeholders at all levels, raise awareness for risk identification and assessment, and implement adaptation.

Consequently, the defined field of actions is later adopted by the MKRO (Ministerial Conference for Spatial Planning) action plan to be incorporated into state-level spatial planning. The resulting list of actions and recommendations effectively became a foundational framework for defining, standardizing, and embedding modern climate strategies within the formal and often legally influential context of regional and state-level spatial plans across Germany. In regard to this study, this established MKRO categorization and definition of various climate adaptation and mitigation strategies is of central importance, as it serves as the key analytical parameter and defines the scope for identifying and classifying these strategies within the German regional planning documents using the LLM-based content analysis."

Natural Language Processing: Foundations and Adaptation in Urban Planning

The domain of urban planning inherently involves extensive analysis of textual data. Documents, as mentioned in the previous chapter, such as comprehensive land use plans, municipal policies, and environmental impact reports, constitute critical sources of information for planning. However, the digestion and analysis of these documents often exceed human analysts' capacity. Traditional qualitative approaches, including manual content analysis, focus groups, and expert surveys, could provide in-depth insights but are both labor-intensive and time-consuming, limiting their scalability across regions and time. For example, Engstrom et al. found that a manual thematic analysis of public meeting transcripts took 73 hours, whereas a semi-automated text analysis tool can produce similar results in 21 hours (Engstrom et al., 2022). However, conventional automated methods can miss nuances in emotions or subtle field languages that require contextual understanding.

These limitations motivate the adoption of Natural Language Processing (NLP) techniques in urban planning, taking advantage of computational power to make sense of unstructured text and turn it into actionable insights.

NLP is a branch of artificial intelligence that enables computers to interpret and manipulate human languages. Historically, NLP began with rule-based and symbolic methodologies in the mid-20th century, where researchers and linguists relied on hand-coded grammatical rules and dictionaries to guide computational language processing (Foote, 2023). By the 1990s, statistical methods were widely adopted, allowing researchers to extract patterns from large text corpora through techniques such as n-grams and part-of-speech tagging. The advances with machine learning and deep learning in the 2010s gave rise to models that learn language representations from data, which is widely used in current-day academia for textual analysis, due to their ability to process massive textual datasets efficiently (Klang et al., 2024).

Despite this potential, the application of NLP within urban planning and related research fields is generally considered to be in its early stages as of 2020. Much of the existing research prior to the date is characterized as exploratory studies with limited sample sizes and lacking a standardized methodology (Fu, 2024). Nevertheless, there is a growing interest among both researchers and practitioners in utilizing NLP tools and especially their successor, Large Language Models (LLMs), for urban applications. A systematic review of individual studies has revealed that NLP is being applied across several key areas within urban planning research:

1. **Urban governance and management:** NLP is used to analyze long-term citizen feedback, problems, and engagement levels from crowd-sourcing platforms like Twitter, Google Maps, and forums (Abalı et al., 2018; Ebrahimi & Ehsan Bakhsh, 2025; Estévez-Ortiz et al., 2016). It's also used during public emergencies, like during disaster responses, to identify citizen needs from geo-tagged social media posts and other channels of information (Hong et al., 2018; Hu et al., 2019). Other applications include analyzing emergency call records and online reviews for crime pattern detection (Cai, 2021).
2. **Public Health:** Social media data were used to collect patterns and perceptions of public health events, for example influenza outbreaks or air pollution events (Riga & Karatzas, 2014; Wakamiya et al., 2018). During the 2019 COVID pandemic, there was extensive research on assessing residents' perceptions of their living environments, lifestyles, and health-related behaviors. For example, researchers in China compared the social media data before, during, and after the pandemic to understand the psychological and behavioral impacts of lockdowns (Liu et al., 2021; Tsao et al., 2021; Zhu et al., 2023).
3. **Urban Design and Infrastructure:** Researchers extract public concerns regarding physical structures, for example, public transportation, Points of Interest (POIs), and landmarks, through text and hashtags associated with geotagged photos on multi-media platforms like Instagram (Iaconesi, 2015; Jang & Kim, 2019).
4. **Analysis of Planning Documents:** Similar to the approach of this thesis, researchers apply NLP directly to formal planning documents like comprehensive plans, resilience strategies, or regulatory texts to extract key information, classify content

into themes or policy areas, or extract specific requirements for compliance measurement (Brinkley & Stahmer, 2021; Guyadeen et al., 2019; Zhang & El-Gohary, 2016).

Unanimously agreed in the above literature, the adoption of NLP in urban planning offers several significant benefits. First, it improves the usability of vast urban datasets, particularly unstructured textual information that is otherwise difficult or costly to analyze systematically. It expands the research scope and scale with reduced labor and time cost, allowing for comparisons across numerous documents and jurisdictions. Furthermore, automated methods, especially while handling large corpora, introduce higher consistency and reduce subjectivity compared to human coders (Cai, 2021).

However, noteworthy challenges and limitations hinder the widespread and effective use of NLP in Planning. Data acquisition and quality remain major hurdles, as non-representativeness and noise lead to inevitable biases. Social media and online comments are not a perfect cross-section of the population, representing more tech-savvy or more vocal groups. Planning documents, especially historical documents, suffer from issues of inaccessibility (e.g., plans not readily available online or in machine-readable formats) and data incompleteness or loss during the process of digitalization (Piotrowski, 2012). Finally, planners and urban researchers may lack the necessary computational skills and resources to implement sophisticated NLP models.

From the perspective of methodological limitations, many traditional NLP techniques used in previous studies fail to achieve a deeper contextual understanding of language. For example, Schmitt's and Brinkley and Stahmer's studies, based on keyword searches and LDA topic models, treat documents as "bags of words," ignoring word order or sarcasm, ambiguity, and context (Brinkley & Stahmer, 2021; Schmitt, 2016). This leads to limited or biased interpretations - for instance, a word frequency analysis might flag the term "wind energy" as a frequent topic in the planning documents, but without context, it's unclear if it's positively associated (call for more wind energy in the area) or negative (potential harm to the local ecosystem with introduction of wind turbines) with the region. Furthermore, the current lack of standardized datasets and evaluation metrics for NLP tasks in planning makes it difficult to rigorously compare the performance of different methods or validate the results (Fu, 2024).

Shifting to Large Language Models

In summary, current NLP approaches in urban planning have achieved effective pattern recognition and scaling up analysis, but struggle with depth and longitudinal analysis of understanding. They often require significant human oversight to ensure findings are contextually accurate and conduct cross-document or inter-governmental analysis, given that planning operates within a complex web of highly specialized documents and governance levels. These limitation motivates the exploration of more advanced NLP techniques, such as Large Language Models (LLMs), which have improved abilities in context comprehension, multi-language and multimodal input handling, and more accessible input/outputs that can be easier for practitioners to interpret.

LLMs are a class of AI models distinguished primarily by their enormous training scale. They typically contain billions to trillions of parameters - the variables in their training and decision-making process, which allows them to have a broad knowledge of the real world, capture nuances and patterns in long input text, and make sense of complex linguistic relationships and inferences in human language (D. Xu et al., 2023). LLMs represent the frontier of NLP techniques, and are distinguished from earlier NLP techniques through their scale and adaptability. First, unlike a simple bag-of-words model, an LLM builds rich contextual embeddings through its parameters. They "read" texts like a human, considering the surrounding words and broader contextual knowledge (Zhou, Lin, & Li, 2024). Second, LLMs are usually trained in a general-purpose way, making them adaptable to various downstream tasks with minimal or no task-specific training and human intervention (technically known as *few-shot* or *zero-shot learning*). While traditional NLP pipelines require specific technical knowledge and repeated training of separate models for each task, LLMs can be prompted in plain language like "summarize the topics covered in the plan," to perform a task. The increased accessibility for practitioners, and often sensible results without additional knowledge input, show their remarkable flexibility and potential for both real-world planning and planning-related research.

Moreover, many LLMs are inherently multilingual, given the fact that models such as XLM-RoBERTa or GPT have been trained on dozens of languages from the online corpora, meaning they can process and generate responses in various languages at the same time (Rathje et al., 2024). This cross-lingual ability is crucial for comparative urban studies that across regions with different languages, which also lowers the threshold for international scholars to make sense of planning documents outside their language scope.

Current studies using LLMs

Since LLMs are still a very recent innovation, their use in urban planning is still in its infancy. Researchers are exploring their use mainly in enhancing service delivery and public engagement given the high accessibility of LLMs. One line of exploration is using LLMs to enhance participatory planning, as Zhou et al. proposed a framework where LLMs are used to simulate stakeholders in the participatory planning process (Zhou, Lin, Jin, et al., 2024). In their approach, LLMs played the role of planners and residents with diverse profiles, iteratively refining land-use plans based on the feedback from the models. Allegedly, the LLM-driven process achieved high agreement and satisfaction rates, comparable to or even exceeding traditional human-led planning workshops (Zhou, Lin, & Li, 2024).

Another significant area of application is the intersection of LLMs and specialized tools like Geographic Information Systems (GIS). The goal is to create more intuitive, natural language interfaces for planning tools, enabling users with limited technical expertise to perform geospatial analyses by simply describing their requests in human language (Gramacki et al., 2024; Mansourian & Oucheikh, 2024). Furthermore, LLMs are being benchmarked for their abilities in interpreting information generated from performed spatial analysis and presented on existing maps (L. Xu et al., 2025). These examples showcase LLMs' ability to handle complex, interactive planning tasks through multimodal input, including plain languages and other forms of specialized media.

In terms of the focus of this thesis, planning document analysis specifically, early applications show promise in relevant component tasks, such as understanding spatial concepts and generating relevant outputs like summaries and land use codes. Recent studies, primarily from 2023-2025, could be divided into the following two approaches: adoption of existing general-purpose LLMs like GPT, and finetuning more specialized models. The pioneering study in the prior category is by Fu et al. in 2023, posing the direct question: "*Can ChatGPT evaluate plans?*" (Fu et al., 2023). The authors' experiment to evaluate the quality of 10 climate action plans from U.S. cities using ChatGPT yielded mixed but largely optimistic results, as LLM's evaluation of plan quality agreed with 68% of the human results. Even though it's a notable achievement given the complexity of climate plans, the generic model had difficulties with domain-specific language, with a pattern of discrepancies in technical terms like "form-based code".

On the other hand, researchers also put effort into fine-tuning open-sourced LLMs on a corpus of urban planning text to build their understanding of planning terminology and writing styles. Such models are expected to address the above issue of lacking the specialized knowledge required for planning. For example, recent works have introduced benchmarks and fine-tuned models for planning, with an improved performance for domain-specific terms like understanding detailed zoning regulations (Zheng et al., 2024).

Remaining Challenges

While LLMs address some barriers in manual interpretation and traditional NLP techniques, it's important to acknowledge that they introduce new considerations. Accuracy and truthfulness of LLM outputs require additional monitoring, compared to probability-and-rule-based NLP techniques. An LLM may hallucinate text that sounds plausible but never appeared in the document; Hidden Bias is another concern, as LLMs may carry biases from their training data and thus influence their interpretation of the text. For instance, generic LLMs with more training data from prevailing models may unconsciously ignore or have biased judgment on non-conventional methods from the text. Technical constraints, like the required expertise and the cost of running specialized, fine-tuned models exist, although models with larger context windows and knowledge are emerging.

Finally, the field of LLMs is characterized by extremely rapid development. New models and techniques emerge constantly in a matter of months, evidenced by the recency of cited literature and the frequent updates to model versions (e.g., from GPT-3 to 4o; Claude 3 to 3.7). This dynamism means the above assessments of capabilities and limitations can quickly become outdated. The most capable generic model, like GPT-4.5, with the ability to search and increased contextual understanding, likely outperforms its fine-tuned predecessor from Zheng's study.

Chapter 3. Methodology

Having explored the existing landscape of content analysis techniques, this chapter introduces the LLM-based pipeline developed for this study with regard to German regional planning documents. The methodological framework is designed to overcome the previously mentioned shortcomings with the advanced natural language understanding capabilities of LLMs, achieving a more nuanced qualitative understanding of current adaptation practices. Specifically, the analytical process, which will be detailed in the subsequent sections, begins with manual gathering and preprocessing of the corpus, transforming digitalized planning documents to standardized segmented text. The core analysis then employs the ChatGPT-4o model to identify and calculate the density score for each region as a proxy for planning emphasis. Finally, the methodology compares a collection of relevant real-world indicators with the results through visualizations of correlation and spatial distribution to explore patterns and relationships.

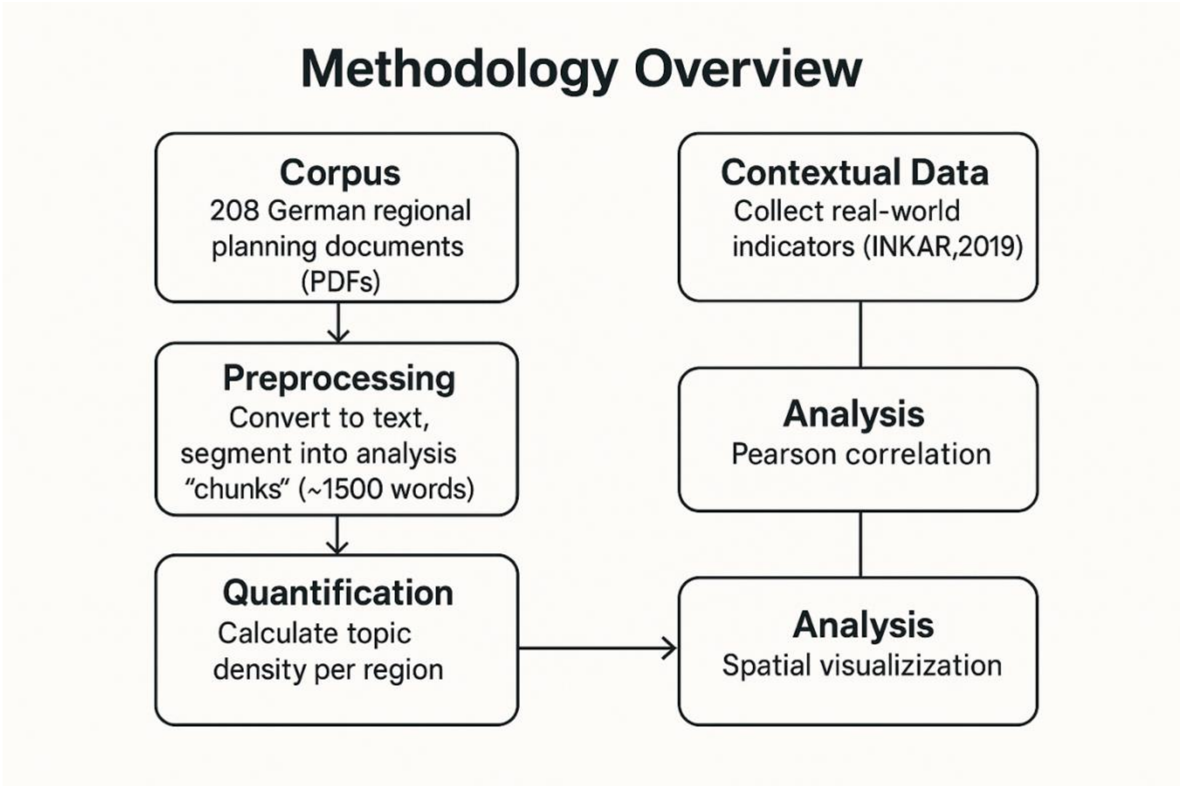

Figure 1: Analysis Workflow

Data Collection and Analysis

Regional Plans

We gathered a total of 222 planning documents, amendments, and partial updates from *Bundesinstitut für Bau-, Stadt- und Raumforschung* (BBSR) for analysis. After excluding files that are corrupted and unable to convert to plain text, we conducted analysis on a total of 208 documents from 110 planning regions with a time span of over 30 years, from the 1980s to 2023.

The regional plans were obtained in PDF format and then pre-processed into plain text format to ensure uniformity and readability. Documents were then segmented into "chunks", each approximately 1,500 words or 20,000 characters long. This chunking strategy was chosen after several trials to balance granularity with thematic understanding, considering the limitations of LLM's context window, ability of information extraction, and the issue of hallucination. While modern LLMs, like ChatGPT 4o, Claude Opus, or DeepSeek claimed to have a large enough context window - the amount of text to effectively analyze in a single pass - to capture a whole planning document, we found that larger chunks risk overlooking smaller topics, truncated outputs, or loss of coherence. Conversely, chunks that are too small may lead to fragmentation of contextual information, making it difficult for the model to capture overarching themes. The chosen chunk size is thus aimed to maximize thematic continuity while avoiding hallucination - a known issue where the model generates irrelevant or spurious context when the input text is incomplete.

Climate Topics

Climate Topics used in this analysis are drawn from the MKRO (Ministerial Conference for Spatial Planning) action plan.

Table 1: Climate-related topics from the MKRO action plan.

Topic (German)	**Topic (English)**	**Explanation**
Energieversorgung	Energy Saving and Supply	Topics related to energy saving and renewable energy
Kohlenstoffsenken	Carbon Sinks	Creation and protection of Carbon reservoirs and sinks
Hochwasserschutz	Flood protection	Preventive measures regarding river basins and flooding
Küstenschutz	Coastal protection	Protecting the coast from the effects of climate change
Schutz der Berggebiete	Protection of mountain areas	Protective measures regarding mountain areas
Schutz vor Hitzefolgen	Effects of heat	Heat-related mitigation strategies
Wasserknappheiten	Water shortages	Measures regarding groundwater, dryness, and drought
Tourismus	Tourism	Measures regarding over-tourism, and adaption to climate change
Lebensräume	Habitats	Protection of habitats for animals and plants
Starkregen-ereignissen	Heavy Rain	Protective measures regarding flash flood and rain events
Wälder	Forests	Adaptation of forests to climate change and protection against forest fires

Document Text Analysis

This analysis used ChatGPT-4o, the state-of-art LLM with top-tier multi-language processing and textual processing ability. ChatGPT was prompted with detailed instructions (See Technical Appendix) to identify and interpret the aforementioned climate-related topics. Prompts included topics' names and definitions, each accompanied by a curated list of example keywords. Unlike static keyword extraction, the LLM approach incorporates contextual analysis that evaluates sentences and chapters holistically to determine relevance. This capability reduces false positives and negatives associated with isolated keyword matches. For instance, while traditional methods might classify a sentence mentioning "forest area" as relevant solely based on keywords, ChatGPT assesses whether the term appeared in a climate adaptation context or merely as a descriptive element of land coverage types.

The outcome of the LLM-based analysis is expressed as density metrics, calculated for each topic category. This density reflects the proportion of document chunks containing mentions of specific topics, providing an indicator of thematic emphasis. This approach offers quantitative insights into the prevalence of topics across planning documents, providing insights into patterns of attention or neglect of thematic priorities across regions and time periods. These density matrices ensure the comparability between regions with different numbers or quantities of documents and allow for a more uniform visualization and communication. The density of topic mentions is aggregated at the regional level. Together with the number of chunks, they serve as a proxy for the overall and thematic emphasis within the plans, where a higher number of documents and thematic mentioning density correlate with more effort in certain climate actions.

Real-world Indicators

To better understand the relationship between climate-related topics in German regional plans and their broader socio-political and economic contexts, we collected and analyzed a range of real-world indicators. These indicators provide a quantitative framework to examine how regional external factors correlate with the prioritization and presence of climate-related themes within planning documents.

The data utilized in this analysis were obtained from the official German statistics agency - INKAR (Indicators and Maps for Spatial and Urban Development). These indicators are measured at the special planning region level (*raumordnungsregionen*), mostly overlapping the corresponding planning area (*planungsraum*) of the binding regional plans. To capture the planning documents' long time span while aligning with real-world indicators' data availability, the year 2019's value was used in this analysis.

Categorization of Indicators

As shown in Table 2, the indicators were categorized into four broad groups based on their thematic relevance.

Political

Political variables, including election results and local policy documents, help contextualize the influence of governance, decision-making, and local communities' attitudes on regional climate strategies. The main element of analysis, election results from the 2021 German federal election, were obtained from the official website of the Federal Returning Officer (Bundeswahlleiter).

However, such variables, though included in the analysis, are not yet included in this report due to their high fluctuations over time. Election outcomes, for instance, vary significantly between electoral cycles compared to the other variables that are mostly steady or with a clear direction. This temporal volatility does not align with the longer time span of many regional planning documents that often remain in effect for decades, nor does it reflect the long-term characteristics of the region.

Initially, we hypothesized that Regions with higher support for the Green Party (Bündnis 90/Die Grünen) are more likely to include comprehensive renewable energy planning strategies, such as wind and solar energy development, in their regional plans. It can be reasoned that the Green Party has a strong pro-climate agenda, advocating for renewable energy expansion, carbon neutrality, and decentralized energy systems. Higher voter support for this party may translate into more ambitious climate adaptation and mitigation strategies at the regional level. Similarly, Regions with a higher share of votes for the Christian Democratic Union (CDU/CSU) may emphasize climate adaptation strategies that align with economic and industrial priorities, such as energy efficiency in industry rather than strict decarbonization policies. Right-wing Populist Support, for example, supports towards AfD that with a consistent opposition of ambitious climate policies, should exhibit lower integration of climate topics in regional planning documents, particularly in areas such as emissions reduction and renewable energy expansion.

However, most of the expected correlations are overridden either by national-level mandates on energy saving or geographical and socioeconomic-related topics such as mountain areas and water-related adaptions. Some key discrepancies include that 1. Green

Party regions focusing more on mountain area and water-related adaptation rather than energy supply; 2. AfD-supported areas showing strong flood protection planning rather than rejecting climate planning entirely, and 3. FDP regions prioritizing tourism infrastructure but neglecting key adaptation measures like flood resilience. These differences highlight the influence of local economic, geographic, and federal regulations over political contexts on regional planning.

With that said, we still see that these political variables provide overarching guidelines and policy directions that regional plans are expected to follow. For example, parties like SPD and the Greens, known for aggressive climate action, are more likely to provide more and speedy partial amendments to existing plans, compared to parties with skepticism on climate change. They are also more likely to have more comprehensive and detailed plans, aligning with their proactive attitude towards climate protection.

Geographical/Urban Structure

These indicators capture the physical and spatial characteristics of the regions, providing insights into the natural and built environment's role in interacting with climate priorities. Geographical indicators include Water Area, Forest Area, Settlement Area, Recreation Area, and Per Inhabitant Recreation Area. Urban Structure indicators include Total Population, Population Density, Settlement density, and Rurality (Percent of Rural Population)

Economic

Economic Indicators contextualize the financial and industrial capacity and emphasis of a region, which may correlate with its ability and inclination to implement climate-related actions. Economic indicators include economic outputs like GDP per Inhabitant, Contribution of different Sectors, and indicators of domestic and international tourism like Tourism Accommodation Capacity and Percentage of Foreign Guests.

Miscellaneous

Miscellaneous indicators provide additional context on environmental and waste management practices that can reflect climate strategies or more general attitudes toward environmental issues. These indicators include the percentage of household Recyclable and Bulk Waste, which is a proxy of how well the population in avoiding and recycling waste.

Table 2: List of Real-world Indicators, from INKAR, 2021

Category	Name	Unit	Definition
Political	2021 Electoral Data by Regions	Percentage	Federal Election results of support rate for each party, at the state level.
	Recyclable	Percentage	This indicator calculates the percentage of waste suitable for recycling, which is collected separately from household waste (residual waste) and bulky waste in specially designated collection containers (e.g. yellow bins/bags) or delivered to appropriate collection points. The indicator shows how well the population succeeds in avoiding and recycling waste.
Geographical	Water Area	Percentage	Water-covered areas include flowing water, standing water, harbor basins and, on coasts, the part of the sea that has been de-municipalized on legal grounds (e.g. embankments, changes to port facilities).
	Forest Area	Percentage	Forest areas have a high value for forestry use, the CO2 balance and a high recreational value. They have a strong influence on the landscape.
	Settlement Area	Percentage	Settlement areas include the types of use residential areas, industrial and commercial areas, public facilities as well as recreational areas and cemeteries, minus the areas for mining operations and open-cast mining (so-called mining land).

	Recreation Area	Percentage	Recreational areas are predominantly green, less sealed areas that perform important functions for the local microclimate and groundwater recharge.
	Per Inhabitant Rec.	m²	In relation to the population, the indicator expresses how much area of the city or municipality is theoretically available to everyone for recreation.
Urban Structure	Total Population	Real number	The population (inhabitants) is the number of people who have their permanent residence (main residence) in a regional unit (municipality, district, etc.), including foreigners registered as living there for a longer period of time.
	Population Density	per km²	Settlement density indicates how many inhabitants live per km² of settlement and traffic area and provides information on the efficiency of settlement area use.
	Settlement Density	per km²	Settlement density indicates how many inhabitants live per km² of settlement and traffic area and provides information on the efficiency of settlement area use.
	Pct Rural Population	Percentage	The indicator indicates dispersed settlement structures that are more rural, calculated from the percentage of population that lives in areas with a population density of lower than 150 per km².

Economic	GDP per Inhabitant	Euros	The GDP or gross national product is a measure of the economic performance of a region, and should be interpreted as a measure of prosperity.
	Share of Primary Sector	Percentage	The primary sector includes agriculture, forestry and fishing. GDP or gross domestic product is a measure of the economic performance of a region.
	Share of Secondary Sector	Percentage	The secondary sector includes the manufacturing industry, including construction and mining.
	Share of Tertiary Sector	Percentage	The tertiary sector includes all service sectors (G-T)
	Tourism Accommodation Capacity	Per 1000 inhabitant	Accommodation establishments include hotels, bed and breakfast hotels, inns, guest houses, rest and holiday homes, training centers, holiday homes and holiday apartments, holiday centers, huts, youth hostels and youth hostel-like facilities, campsites as well as preventive and rehabilitation clinics.
	Pct Foreign Guests	Percentage	This is the proportion of overnight stays by people from abroad in accommodation establishments over the course of a calendar year based on all guest overnight stays.

Correlation Analysis

This analysis mainly uses Pearson Correlation Matrices to explore the relationships both within the groups of indicators, and between topic density in climate plans and independent variables, offering a high-level overview and visualization of potential associations. Recognizing the limitations of correlation in inferring causation - including the absence of time-controlled experimental conditions, and the inability to account for unobserved confounders - this method is only positioned as an exploratory tool rather than a statistically definitive analysis. The goal fo the correlation analysis is thus to identify linear relationships between variables and provide an initial understanding of how regional characteristics might relate to climate planning priorities and implementations.

Validation

To ensure the robustness and credibility of the results generated by the LLM-based approach, multiple validation strategies is employed. First, the aggregated results are compared with existing studies with manual evaluation and key-word searching done on a partial portion of the regional planning documents published by BBSR. While a direct quantitative comparison with prior research is challenging due to the differing measurement techniques and analytical scopes, the findings from this LLM-based analysis can be contextualized by examining thematic alignments and conceptual consistencies with these established bodies of literature. While Schmitt, 2016 measured climate strategies' presence and bindingness qualitatively, our LLM's identification of extensive discussion around Flood Protection, Tourism, and Energy Transition can be interpreted as a proxy for the plan's legal engagement with this crucial aspect, which is broadly consistent with Schmidtt's findings. However, discrepancies in some less prominent topics, such as Heat Mitigation that with a high legal emphasis in Schmitt's study, could suggest potential differences in how practitioners and researchers conceptualize certain issue versus how it is framed in official text or understood by the model. Previous studies and surveys conducted by BBSR highlighted the lack of textual clarity and regional cooperation in mountain protection strategies. Our LLM analysis complements this by demonstrating a significant spatialized emphasis in the Mountain Protection action field around higher altitude regions indicates the experienced challenge is also shown in written documents.

Second, these statistics and observations are further verified through qualitative validation, incorporating insights gather from subject-matter experts at BBSR in German. The LLM's outputs are assessed against established field knowledge - such as the expected higher concentration of specific climate adaptation topics in geographically distinct areas like coastal or alpine regions.

Finally, a methodological validation was conducted, which involved a direct comparison of the LLM's performance against both manual coding by the author and traditional keyword searching techniques. However, due to the significant time and resource limitation inherent in Master's thesis research, this comparative analysis is focused on one randomly selected planning document and, for illustrative depth, the performance concerning one representative climate adaptation topic (i.e. Energy Supply) was closely examined. The primary objective of this focused validation exercise is not to definitively prove the LLM's comprehensive effectiveness across all possible scenarios or to establish generalizable performance benchmarks, which would require a much larger and more varied sample. Instead, its purpose is to demonstrate that the LLM is a “good enough” and pragmatically viable tool for the specific, more exploratory ambitions of this thesis.

While the LLM was designed to produce a normalized density measure for thematic content, indicative of its prevalence adjusted for document length, keyword searching yields an absolute count of term mentions. This fundamental difference in output metrics means that a direct quantitative comparison of overall "scores" is not straightforward; therefore, this validation primarily focused on a qualitative assessment of each method's ability to accurately identify relevant concepts and terms associated with specific climate adaptation topics, particularly "Energy Supply" (*Energieversorgung*), and their respective susceptibility to false negatives and false positives.

The keyword search method, when benchmarked against the author's manual validation for the selected document, demonstrated a notable number of false negatives. This indicates that numerous relevant discussions within the document were not captured by the pre-defined keyword list. For the illustrative topic of "Energy supply" (*Energieversorgung*), the keyword search only identified one of the seven pertinent keywords initially provided for this category, namely "*Windenergie*" (wind energy). It failed to detect references to other crucial renewable energy sources such as biomass energy ("*Biomasse*"), which was explicitly present, or solar energy ("*Solarenergie*"). The latter was referred to in ROG’s Field of Action documents using terms "*Photovoltaik*" and "*PV-Anlagen*" (photovoltaics, PV systems), which were intended to be covered by the keyword list but were missed due to slight variations or the search's inability to link synonymous terms. Similarly, hydropower

("*Wasserkraft*"), present as "*wasserkraftnutzung*" in the list of keywords was also overlooked.

This high rate of false negatives for keyword searching can be attributed to several inherent limitations. Firstly, the morphology of the German language, particularly its propensity for compound words ("*Komposita*"), makes it challenging to achieve comprehensive coverage through exact keyword matching. Technical jargons and specific phrases, unless precisely anticipated and included in the keyword list, are easily missed. Secondly, the quality of the source documents, especially older, scanned PDFs processed via Optical Character Recognition (OCR), significantly hindered the efficacy of exact matching. Occasional OCR misreadings, hyphens fragmenting single words, or the incorrect concatenation of text from different columns in the original layout can make specific keywords unsearchable. In the context of "Energy supply," this method did not generate significant false positives.

In contrast, the LLM demonstrated a higher capability in identifying relevant content for the "Energy Supply" topic within the selected document. When prompted to output the exact sentences and keywords it associated with this theme, the LLM successfully identified not only "*Windenergie*" but also terms missed by the keyword search, such as "*Biomasse*" and "*Solarenergie*" (correctly associating it with the document's use of "*Photovoltaik*"). Furthermore, it identified "*Wasserkraft*" (hydropower), even when expressed in related forms. Significantly, the LLM also recognized concepts and infrastructure related to renewable energy supply that were not explicitly part of the initial keyword list but are semantically linked to the core topic. These included terms such as "*Hochspannungsnetz*" (high-voltage grid, essential for transmitting wind-generated electricity), "*Einspeisung*" (feed-in), and "*Umspannstation*" (substation). This suggests the LLM's capacity to move beyond literal term-spotting to capture a broader thematic context.

However, while the LLM-approach, like the keyword search, did not produce notable false positives for the "Energy Supply" category in terms of misclassifying irrelevant topics, the issue of hallucination was observed. Despite prompt engineering efforts to mitigate this, the LLM identified two specific "keywords" as being present in relation to Energy Supply that could not subsequently be located within the original document text. This indicates that while the LLM can be more robust to OCR imperfections and linguistic variations by inferring meaning from noisy text, its inferential capabilities can occasionally lead to the generation or assertion of information not explicitly grounded in the source.

This validation process, though limited to a single document, highlights that the LLM, despite the observed hallucination instances, appears to offer a more comprehensive initial capture of relevant themes. However, it is important to acknowledge, as noted in previous research, that keyword extraction is often employed as an initial assistive step to quickly locate potentially relevant document sections for subsequent detailed manual content analysis, rather than as a standalone analytical method. Similarly, for the LLM-approach, this study integrated multiple pre-analysis finetuning and post-process verification steps with an awareness of potential biases and hallucinations. For the exploratory aims of this thesis - to review a large corpus for the presence and distribution of climate adaptation themes and identify potential correlations - the LLM's capacity to overcome many of the keyword search's limitations suggests it is a more "capable enough" tool.

Chapter 4. Results and Analysis

Internal Real-world Indicator Correlation Analysis

The real-world indicators, as mentioned above, are categorized into Geographic, Urban Structure, and economic variables, each representing distinct aspects of regional characteristics. This section serves as a robustness check to assess potential internal correlations. While these indicators are designed to capture different dimensions of the regional context, they inevitably exhibit internal correlations, particularly within each category. Despite the potential influence to the interpretability, the overall effect remains tolerable and the indicators still provide valuable insights into the relationships between regional characteristics and climate-related planning efforts.

Urban Structure variables show a high degree of interdependence, where population density and settlement display strong positive correlations > 0.8, indicating larger settlements have a higher concentration of population. Rural population, in contrast, is negatively correlated with the urbanization indicators, highlighting the urban-rural divide in different regions. There are also expected positive correlations between economic prosperity and urbanization, where GDP positively correlates with population and settlement density. Conversely, the negative correlation with the Share of the Primary Sector confirms that rural regions remain more reliant on agriculture, forestry, and extractive industries.

Geographic factors, such as Water and Forest Area, exhibit a weaker correlation with general urbanization but are more relevant to regional land use and economic development composition. Interestingly, there’s a divide between Tourism Accommodation Capacity and Foreign Guest Percentage. Regions with a high percentage of foreign guests tend to be more urbanized, with a strong association with GDP per Inhabitant and Settlement Density, suggesting that international tourism is concentrated in major metropolitan areas where they are drawn to business centers rather than natural amenities. In contrast, Tourism Accommodation capacity is positively correlated with Water Areas and Recreational Areas, indicating the coastal and rural regions' prioritization of accommodation availability. This seems to suggest a tourism model where local visitors are attracted to nature-based destinations such as lakes, forests, and seaside resorts, while international tourists gravitate towards well-established popular destinations.

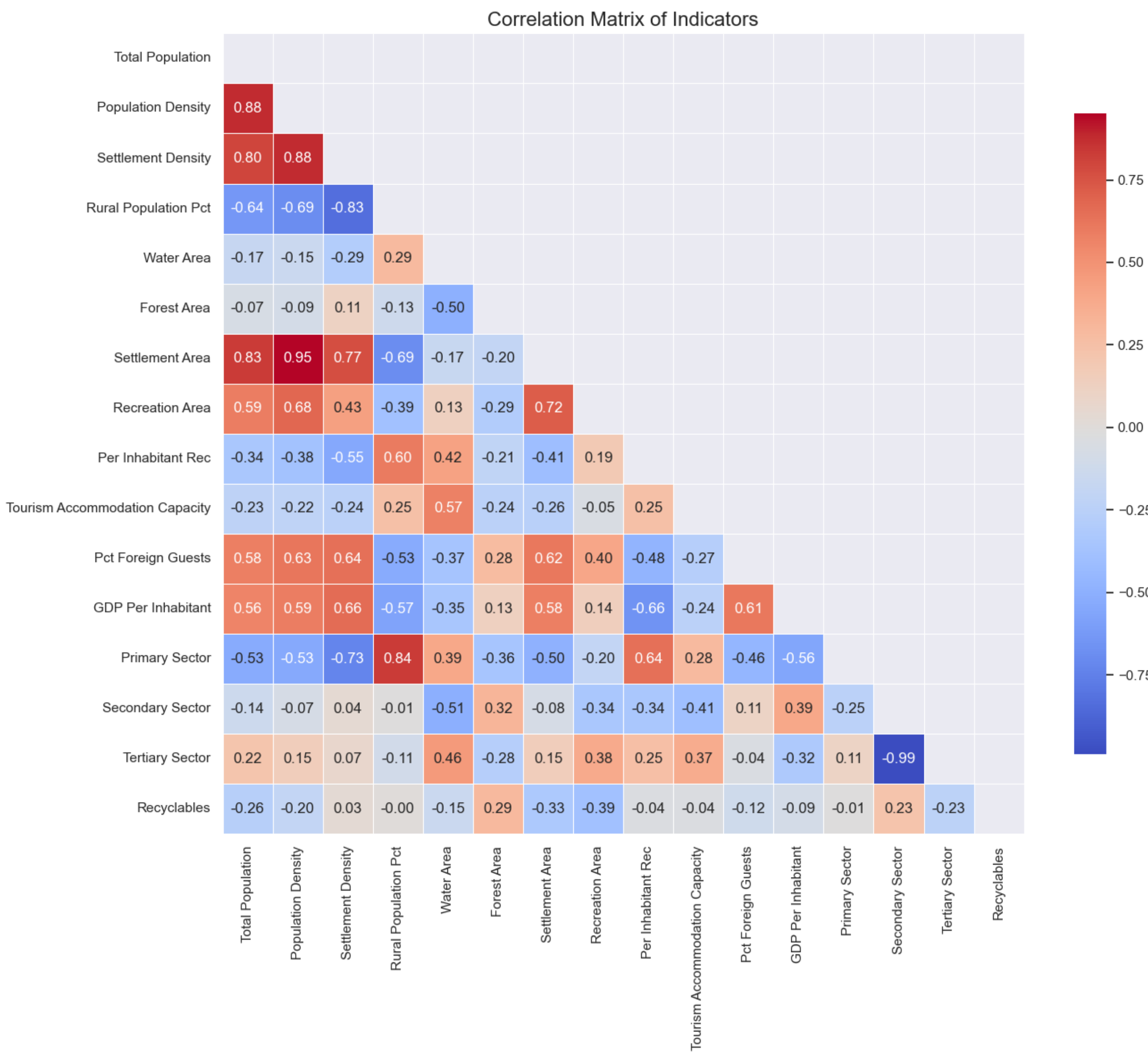

Figure 2: Internal Correlation Matrix: Real-world Indicators

Temporal Topic Analysis

The temporal analysis examines the evolution of climate-related topics in German regional planning documents over time using a longitudinal approach, assessing whether federal legislative interventions and emerging awareness of climate change correspond with notable shifts in planning priorities. The dataset includes approximately 40 documents for each of the 5-year brackets from 2000 to 2020, covering both comprehensive plans and partial updates. Despite the implementation of key deferral policies, including the Renewable Energy Act and climate adaptation frameworks, the frequency of climate topic mentions as well as the number of published documents remains relatively stable over time. Except for a slight increase in efforts around the year 2015, there are no significant peaks aligned directly with the enactment of major legislative acts, suggesting that certain mandates may not immediately translate into explicit updates in planning documents. Even with the presence of partial updates on renewable energy, their overall influence on the total volume of energy supply efforts appears limited.

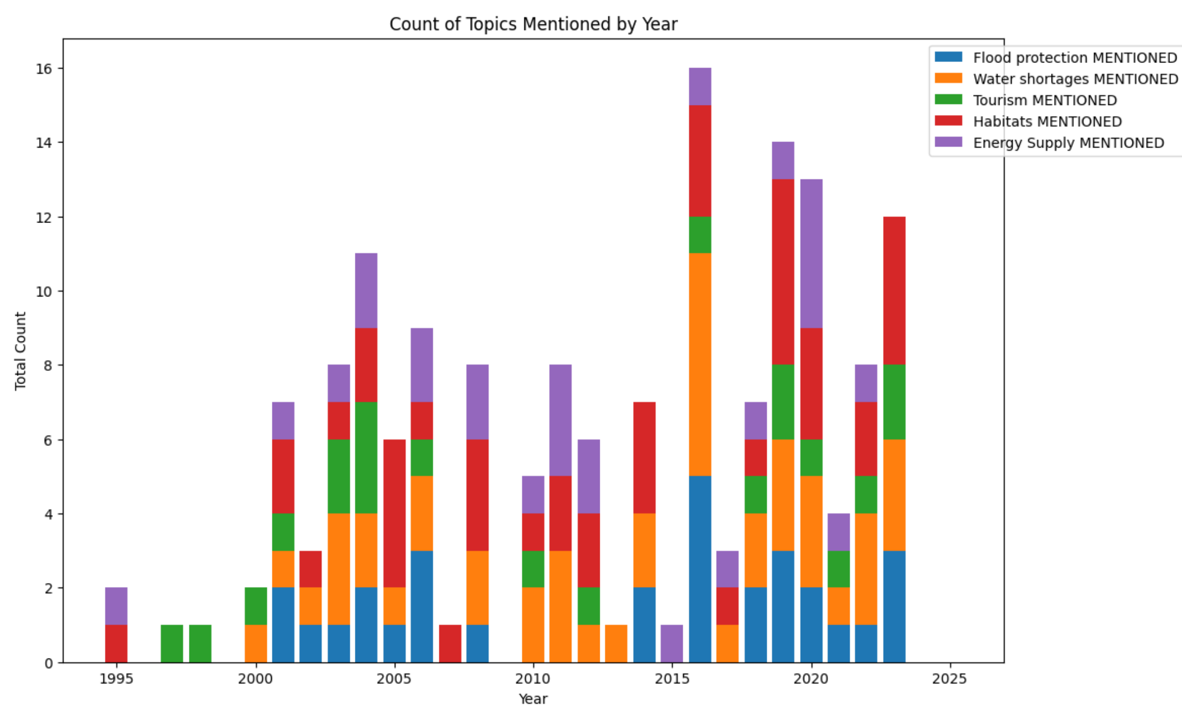

Figure 3: Temporal Distribution of Selected Topics

Three key factors may explain this lack of significant temporal shifts in planning documents:

1. The relatively slow update cycles in Regional Planning Frameworks compared to short-term policy documents lead to the delayed or gradually integrated approach of national-level regulations. For example, the observed increase in climate-related planning efforts in 2015 can be attributed to the delayed policy integration with regard to both the growing public and institutional awareness of climate change and climate policies introduced in the early 2010s.
2. Instead of having immediate and large-scale plan revisions for climate-related topics, national climate policies are often incorporated through gradual amendments and incremental adjustments. While the temporal analysis may reveal the emergences of newer climate-mitigation strategies like the partial updates on wind energy, it does not account for the change of qualitative depth, variation in strategies, or the implementation efforts within existing topics. The progressive integration of newer ideas, where previous topics are often continued in the next version, may lead to the overestimation of the uniformity of climate planning efforts across time periods.

Internal Climate Topics Correlation Analysis

The correlations reveal that many climate topics coexist due to shared goals or synergistic strategies, meaning that a stronger emphasis on one issue often promotes parallel commitments in other areas and contributes to broader overall climate mitigation incorporations. The following by-category analysis provides a more detailed illustration of the interrelationships between different planning goals:

Ecosystem-based solutions, such are carbon sinks, forests, and habitats show strong, positive correlation with one another, reflecting the integration of nature-based solutions in climate adaptation. Forest restoration, for instance, not only enhances carbon sequestration but also simultaneously conserves biodiversity. Additional essential ecosystem services - for example, wetlands' ability to reduce flood risk, are also observed in the positive correlation between habitats and flood prevention.

Water-related concerns, such are flood, heavy rain, and water shortage protection, also display moderate positive correlations as expected. This signifies that regions prone to storms or droughts frequently employ integrated water resource management tactics that address these extreme weather events as a whole.

Geographically Distinct Strategies, for example, mountain and coastal protection in relation to heat mitigation, show modest or negative correlations that align with their geographic exclusivity. For instance, coastal regions have less focus on heat mitigation due to the natural cooling effect of water areas, whereas tourism-related strategies more frequently coexist in these areas with natural attractions. Similar effects are also reflected in **socioeconomic and sectoral concerns**, where tourism is also moderately correlated with water shortage and heavy rain. This implies that tourism destinations (often urban cores, as illustrated in the previous chapter) susceptible to climate extremes prioritize resilience strategies to protect the tourism economies. Meanwhile, energy supply shows a moderate positive correlation with water shortage and coastal protection, reflecting how renewable energy projects (e.g., offshore wind farms) may become integral to coastal areas. This correlations shows that most of the planning documents are effectively diverged based on location-specific hazards.

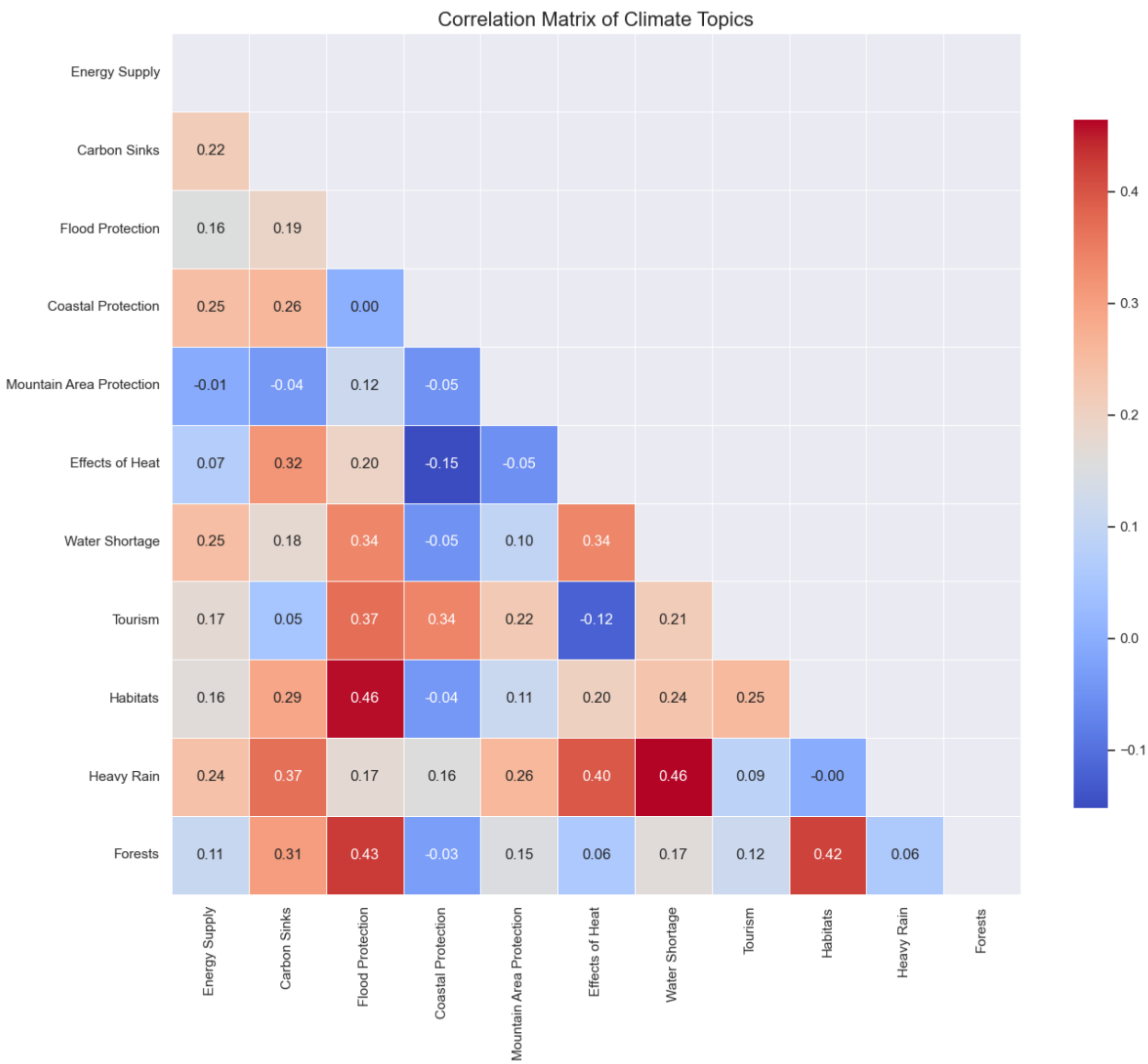

Figure 4: Internal Correlation Matrix: Climate Strategies

Correlation with Real-world Indicators

This correlation matrix summarizes the vertical trends of how certain real-world indicators relate to various climate topics.

1. Urbanization, particularly in regions with higher GDP and secondary sectors, presents unique challenges and opportunities in addressing climate-related issues.

Densely populated, economically advanced, and massively transformed regions are associated with amplified urban challenges. This is reflected in strong, positive correlations to Effects of Hear, Flood Protection, and Water Shortage. However, these areas are also better equipped with economic resources and greater public awareness to incorporate comprehensive mitigation strategies.

2. Certain climate topics, however, display relative uniformity in their emphasis across regions, driven by federal-level legislation mandating their inclusion in planning documents. For example, Flood Prevention and, especially Energy Supply are prioritized in both rural and urban areas regardless of the indicator differences. While this uniformity reflects the success of national policies in addressing pressing climate challenges, it also raises potential concerns regarding efficiency and effectiveness. Without a deeper analysis of the text, there is potential for resource misallocation or waste, as uniform policies might fail to account for regional nuances. The risk of policy stagnation or superficial compliance also exists, where plans meet federal requirements on text but lack follow-through or enforcement.
3. Indirect Proxies, like Recyclables and Bulk, non-recyclables emerge as valuable indicators for regional sustainability efforts, correlating positively with a wide range of climate topics. Regions with higher recycling rates, and lower non-recyclables rates are associated with more proactive approaches to climate adaptation and mitigation in planning frameworks.

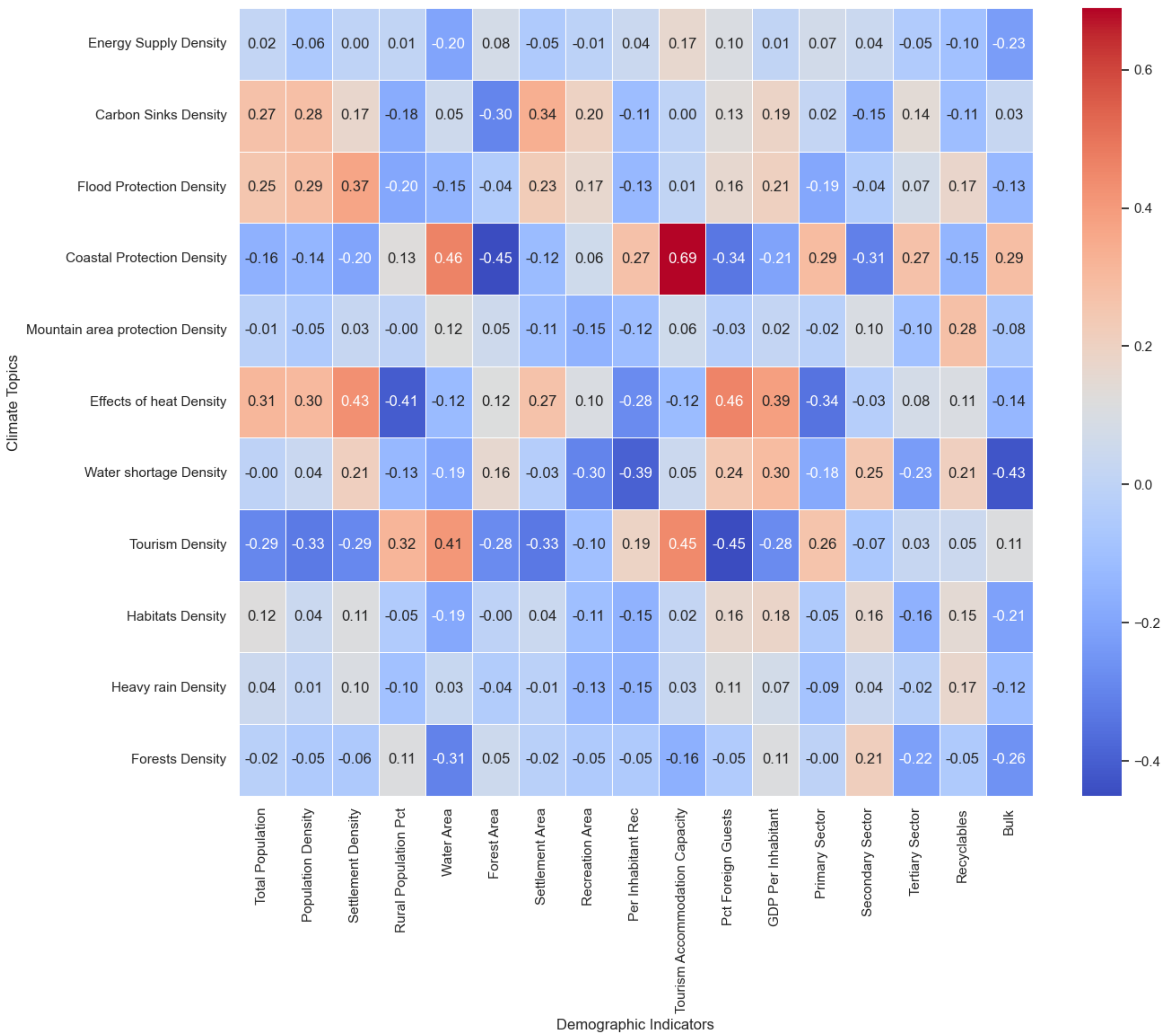

Figure 5: Correlation Matrix for Climate Strategies and Indicators

Spatial Distribution

The following maps depict the levels of engagement of different climate topics in regional plans, with darker colors indicating a higher emphasis. Lighter regions correspond to lower levels of emphasis, hatched areas represent no mention of the given topic, while transparent areas represent regions for which planning documents are unavailable.

Energy

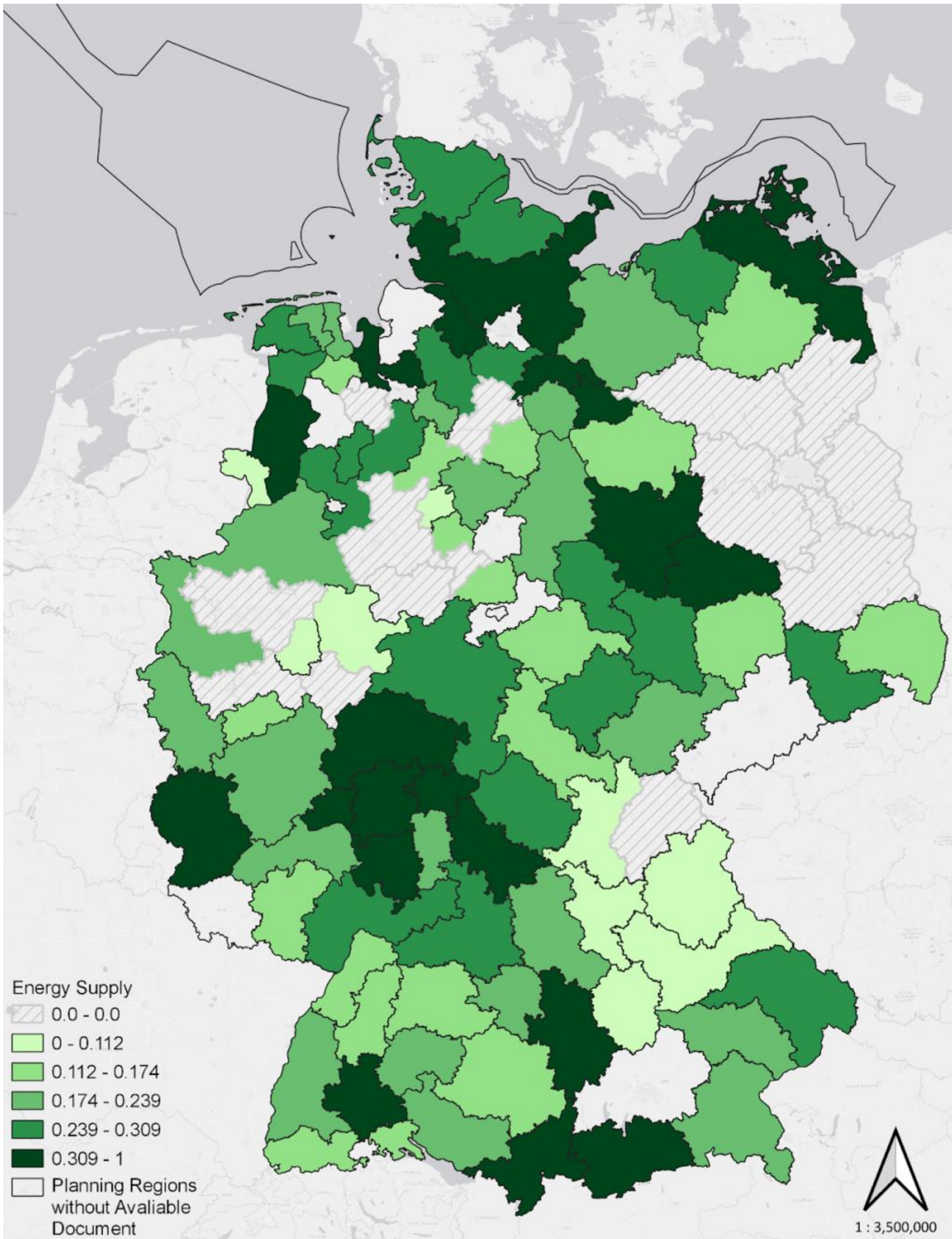

Figure 6: Spatial Distribution - Energy

The spatial distribution of the "Energy Supply" shows varying but overall high levels of engagement across the country. This universal commitment to a clean energy supply is driven significantly by a comprehensive federal legislative framework and the abundance of corresponding partial updates of regional plans aimed at transforming the energy supply towards renewable sources. Key legislation, such as the Renewable Energy Sources Act (EEG) since 2000, and more recent acts like the Wind Energy Area Requirements Act (WindBG) and the Solar Package I, mandate specific actions and targets, intensifying the role and requirements of spatial planning. The WindBG, for instance, requires federal states to designate specific land percentages (1.4% by 2027, 2.0% by 2032) for onshore wind, leading to nationwide planning action and necessitating significant adjustments in regional plans (Dosch, 2025, p. 114).

Spatially, the map showed a distinct stronger focus on energy supply planning is evident in Northern Germany, particularly in coastal states. The focus in planning documents demonstrates both existing efforts in implementing clean energy projects, current challenges in phasing out traditional energy sources, and the regional potential of renewable energy sources. Schleswig-Holstein and Mecklenburg-Corpommern have the highest share of renewables in their power generation mix across the nation, primarily due to significant onshore and offshore wind energy potential and projects. Niedersachsen also shows substantial installed wind capacity, as well as increasing grid expansion planning to transport energy southward. Conversely, Southern Germany, particularly industrial regions like Bavaria and Baden-Württemberg, demonstrates a planning focus corresponding with different topics - solar photovoltaic (PV) capacity and significant energy demand. While Bavaria leads in overall installed renewable capacity, driven largely by solar and biomass, it and these southern states face challenges in compensating for phased-out nuclear and coal power solely through current renewable expansion rates, which also leads to the extensive discussion of renewable energy programs in their planning document (Hartz et al., 2023). In the West, North Rhine-Westphalia, with its history of coal mining in the Rhenish lignite area, signifies the dual planning challenge of managing the fossil fuel phase-out and accelerating renewable deployment.

However, referring to the correlation matrix, there are no significant correlations between **Energy Supply Density** and real-world indicators. This lack of correlation suggests a planning landscape heavily influenced by uniform federal policy objectives. While the actual implementation and generation of renewable energy are intrinsically linked to regional resource availability (e.g., wind speeds in the North, solar irradiation in the South), the planning activity itself, particularly the designation of areas, appears increasingly driven by national mandates like the WindBG targets. As of late 2023, nationally designated areas for wind power (0.5%) significantly lagged behind the federal targets (2% by 2032), according to the spatial observation of BBSR, *Raumordnungsplan-Monitor*, ROPLAMO. This indicates that all regions, regardless of their current resource exploitation levels or installed capacity, are under substantial pressure to intensify planning efforts to meet these overarching national goals. Central regions, potentially lacking prime renewable resources, are nevertheless required to include energy supply planning in their planning documents to align with national objectives. Thus, the observed decoupling between the emphasis in spatial plans and specific local resource endowments or current implementation levels exemplifies the top-down planning scheme in Germany. The role of spatial planning is strongly shaped by the federal regulations and national objectives, regardless of the regionally varying physical realization and resource conditions.

Carbon Sink

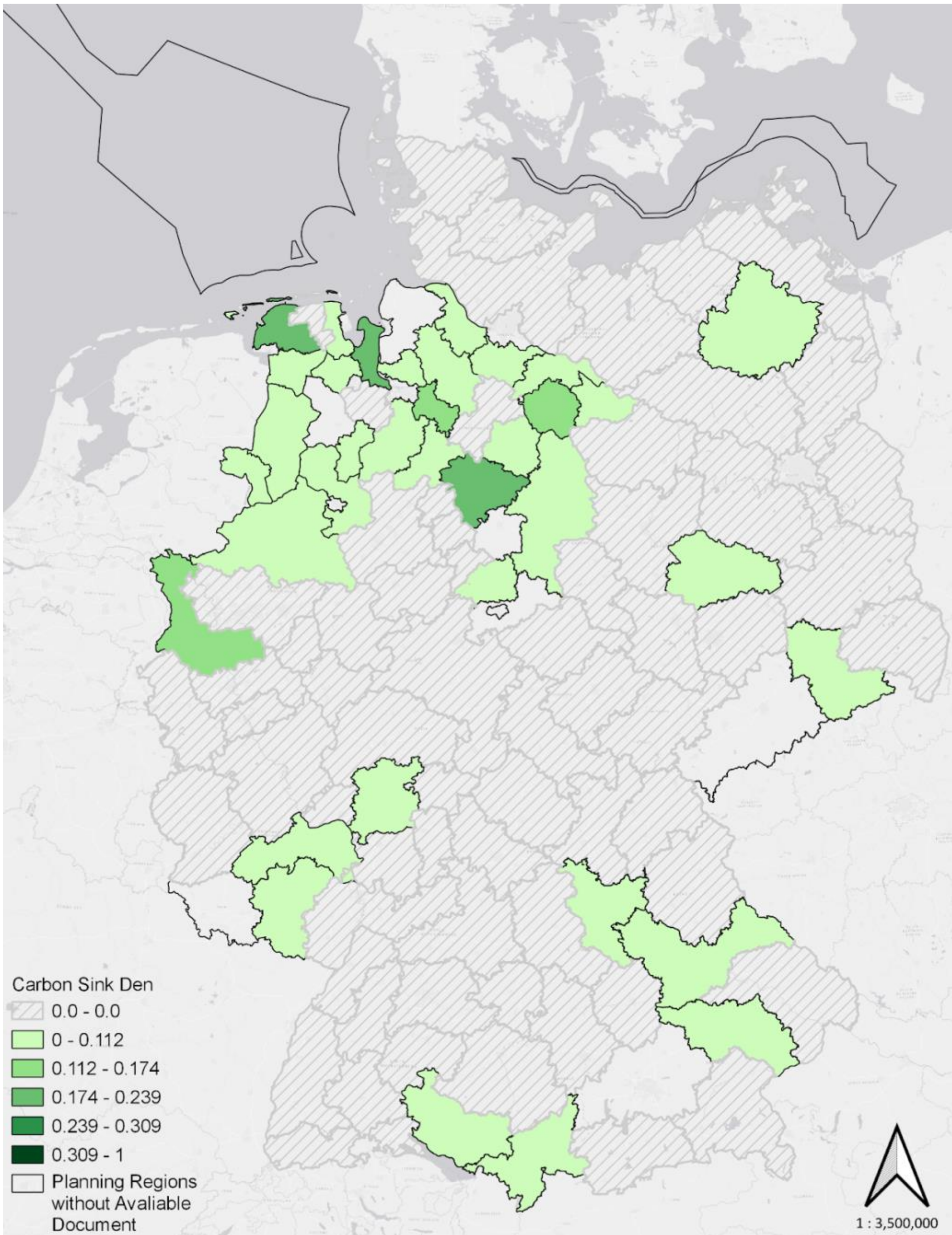

Figure 7: Spatial Distribution - Carbon Sink

The explicit integration of natural carbon sinks into German spatial planning documents appears limited and regionally concentrated. While the general protection of open space is a common topic in both regional plans and relevant reports, specific designations on preserving the land's carbon sequestration function for ecosystems like forests, peatlands, and moorland are not widely recognized (Dosch, 2025). Notable exceptions exist, such as in Lower Saxony, Saxony-Anhalt, where the state spatial planning program mandates peat conservation, and in some parts of the southern states like Bavaria, where the latest state development plan enables climate protection through peatland conservation. Overall, only about 25% of the evaluated regional plans included principles related to maintaining and enhancing natural carbon sinks, often cross-referencing forest expansion or general protection. Specific objectives related to peatland conservation are often absent.

However, the correlation matrix reveals that Carbon Sinks Density is positively correlated with Population and population density, and the percentage of recreation areas, but negatively correlated with rural population percentage and forest area. This shows the growing focus in urban areas on nature-based solutions to address climate change despite limited physical space for natural carbon sinks like forests or wetlands. Recreational areas in urban regions, such are parks, botanical gardens, or open spaces, often serve as artificial carbon sinks and are included as implementations of carbon sink strategies for climate mitigation.

Surprisingly, forest-rich regions show less statistical emphasis on carbon sinks in planning documents. The negative correlation can result from the spatial planning instruments' limited competence regarding the management of forests per ROG. While regional plans often contain guidelines for protecting forest areas from competing land uses, they seldom directly pose specific forestry practices for carbon sequestration beyond general, passive conservation principles. The forests may be perceived as fulfilling their carbon sink function inherently, leading to the lack of explicit mention of carbon sequestration in planning mandates over aspects like biodiversity or timber production.

Flood Protection

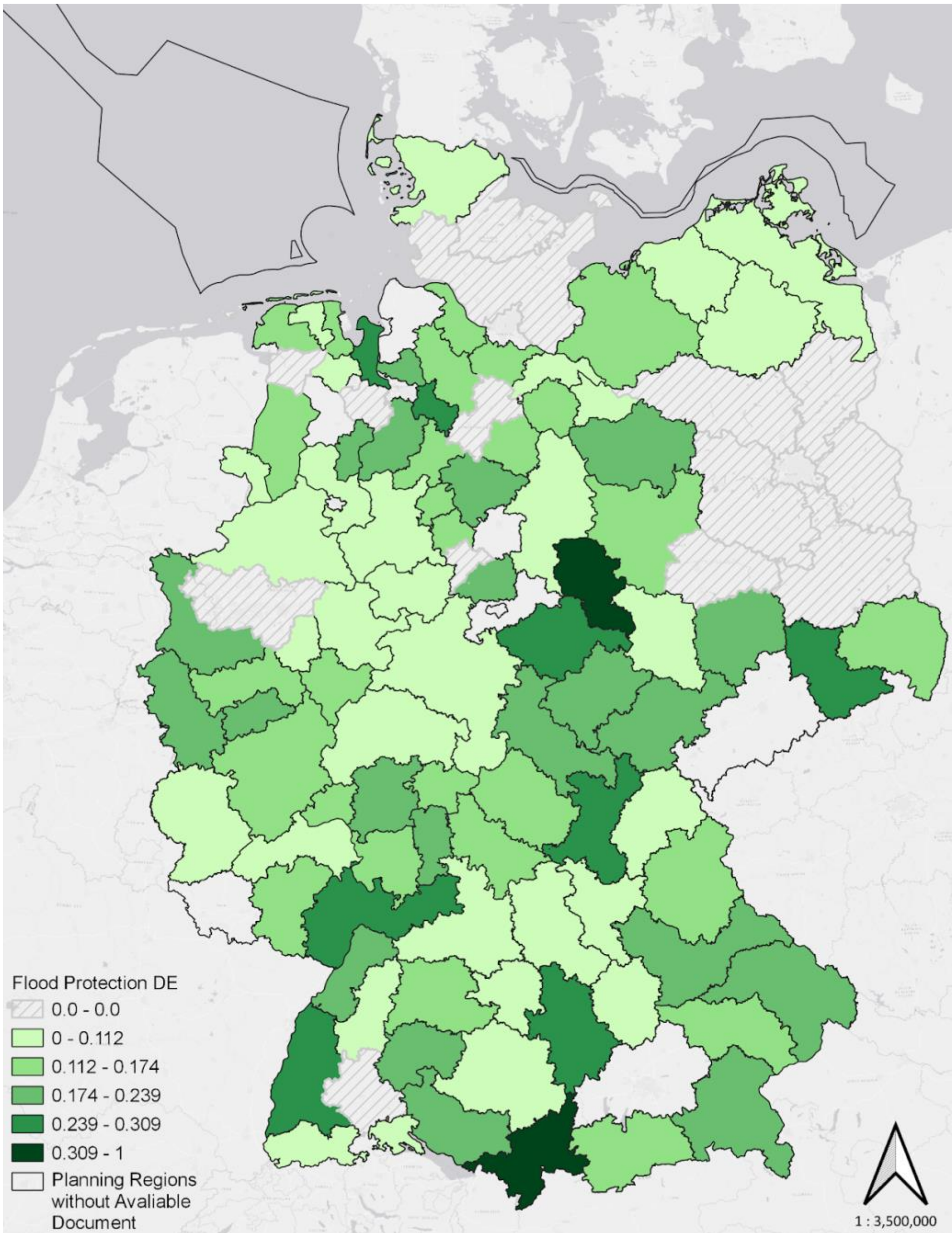

Figure 8: Spatial Distribution - Flood Protection

Flood Protection represents a nearly universally addressed topic within German spatial planning documents, reflecting its significance in both historical land use modifications and climate change mitigation. Its emphasis is higher in regions susceptible to riverine flooding, including areas along major rivers, such as the Danube and its tributaries in Southern Germany, the Rhine corridor in the West, and the Elbe, with major flood events in recent decades. Previous studies have shown that securing designated flood plains (*Überschwemmungsbereiche*) and retention areas (*Retentionsraum*) has been a common planning objective (Schmitt, 2016). The universal incorporation of flood protection is further reinforced by the Federal Spatial Planning Act for Flood Protection (*Bundesraumordnungsplan Hochwasserschutz*, BRPH) in 2021, mandating a risk-based approach. Specific regional plans are prone to flooding, such as those for Oberes Elbtal/Osterzgebirge and Leipzig-Westsachsen, extended beyond the federal requirements and developed comprehensive, multi-stage concepts for flood prevention and risk mitigation. The first two stages aim to help reduce the probability of flooding through improving the water storage capacity of the soil and building water retention infrastructures. In the later stages, for example adjustment of land use in high-risk flood areas, minimizes the possible damage when the first stages fail to prevent flooding (RPV OEOE, 2020).

The positive correlation observed between flood protection planning emphasis and indicators of urbanization, economic development, and population density aligns with the increasing flood risks in developed areas. Urbanization leads to increased surface sealing and decreased natural floodplains, reducing the natural retention capacity and increasing runoff. Simultaneously, increased economic developments lead to the concentration of high-value assets and populations in vulnerable locations. Consequently, spatial planning in these densely populated and economically significant regions prioritizes the protection of settlements. Conversely, the relatively lower planning emphasis observed in sparsely populated regions, for example, Eastern Germany or forested areas like the Black Forest, may be linked to the greater natural flood mitigation capacity through existing forest, wetlands, and less altered landscapes. These areas have received lower urgency in terms of restrictive planning interventions.

Coastal Protection

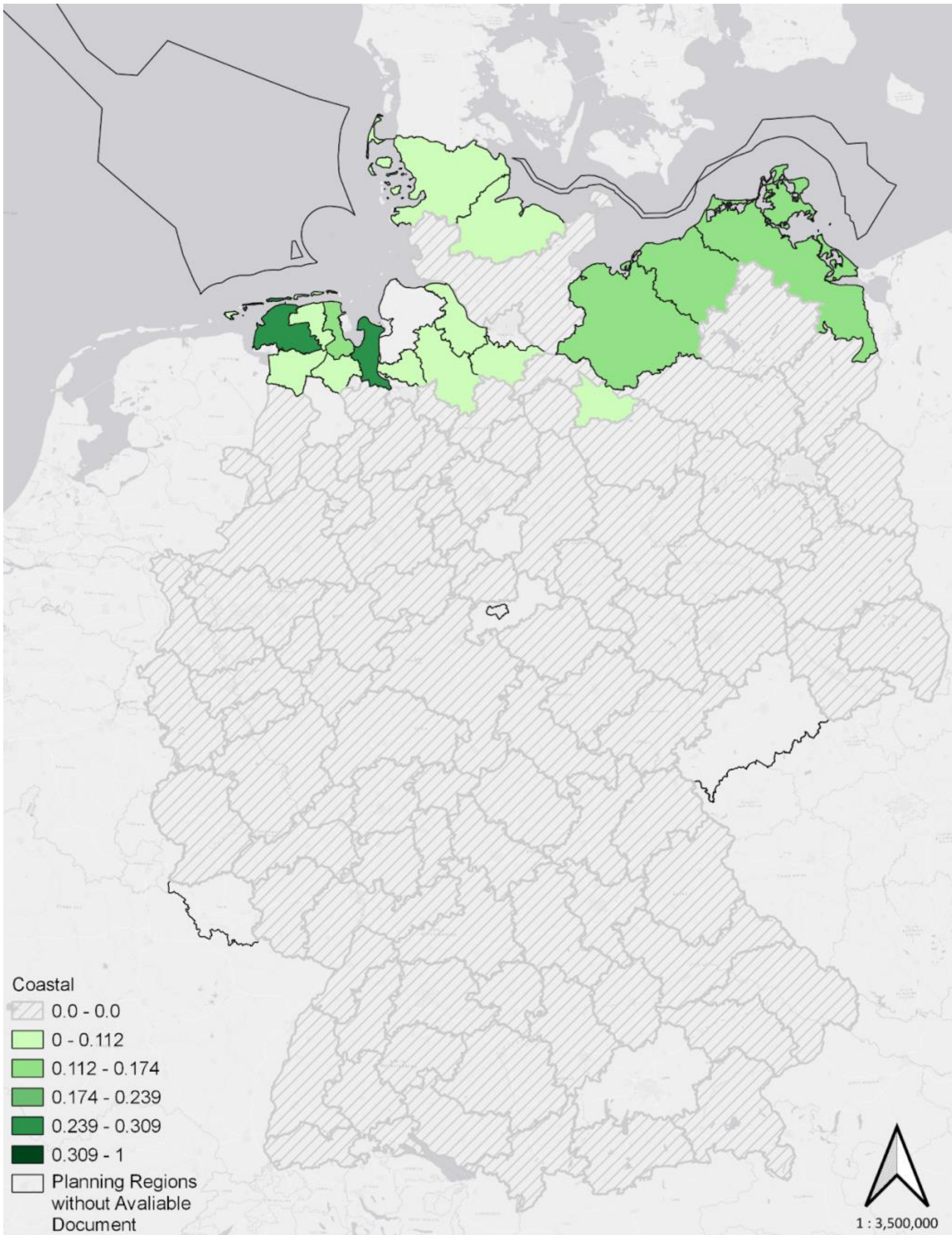

Figure 9: Spatial Distribution - Coastal Protection

Planning for coastal protection is inherently geographically concentrated in Germany's northern coastal regions along the North Sea and Baltic Sea, directly driven by the physical vulnerability of these areas. Primary threats in these areas are identified as sea-level rise - a 42 cm increase at the Cuxhaven gauge since 1843, and the more intense strom surges (Arns et al., 2017; DWD – Deutscher Wetterdienst, 2023).

The positive correlation with the primary sector likely reflects interdependencies between coastal protection measures and outcomes. For example, spatial planning documents include designations securing extraction sites for clay and sand (*Kleientnahmestellen*, *Sandentnahmestellen*) for coastal protection measures like dike construction and reinforcement, contributing to the development of the local primary sector (Hartz et al., 2023). In addition, another goal for coastal protection is to safeguard agricultural land in low-lying regions and coastal fisheries. However, fisheries are less commonly included in coastal protection frameworks, compared to other direct challenges like increasing droughts, rising water temperatures, or decreased marine biodiversity, as exemplified in Mecklenburg-Vorpommern's local LEPs (Kambor, 2013).

The observed positive correlation with tourism and tertiary sector activities suggests a potential positive influence on coastal protection prioritization through economic development. Coastal areas are significant settlement and economic zones, including important tourist destinations. Safeguarding infrastructure is thus crucial for maintaining the economic viability of these regions. Therefore, while mostly driven by physical vulnerability, the emphasis in coastal planning also likely incorporates the high economic values associated with tourism and tertiary activities.

Mountain Area Protection

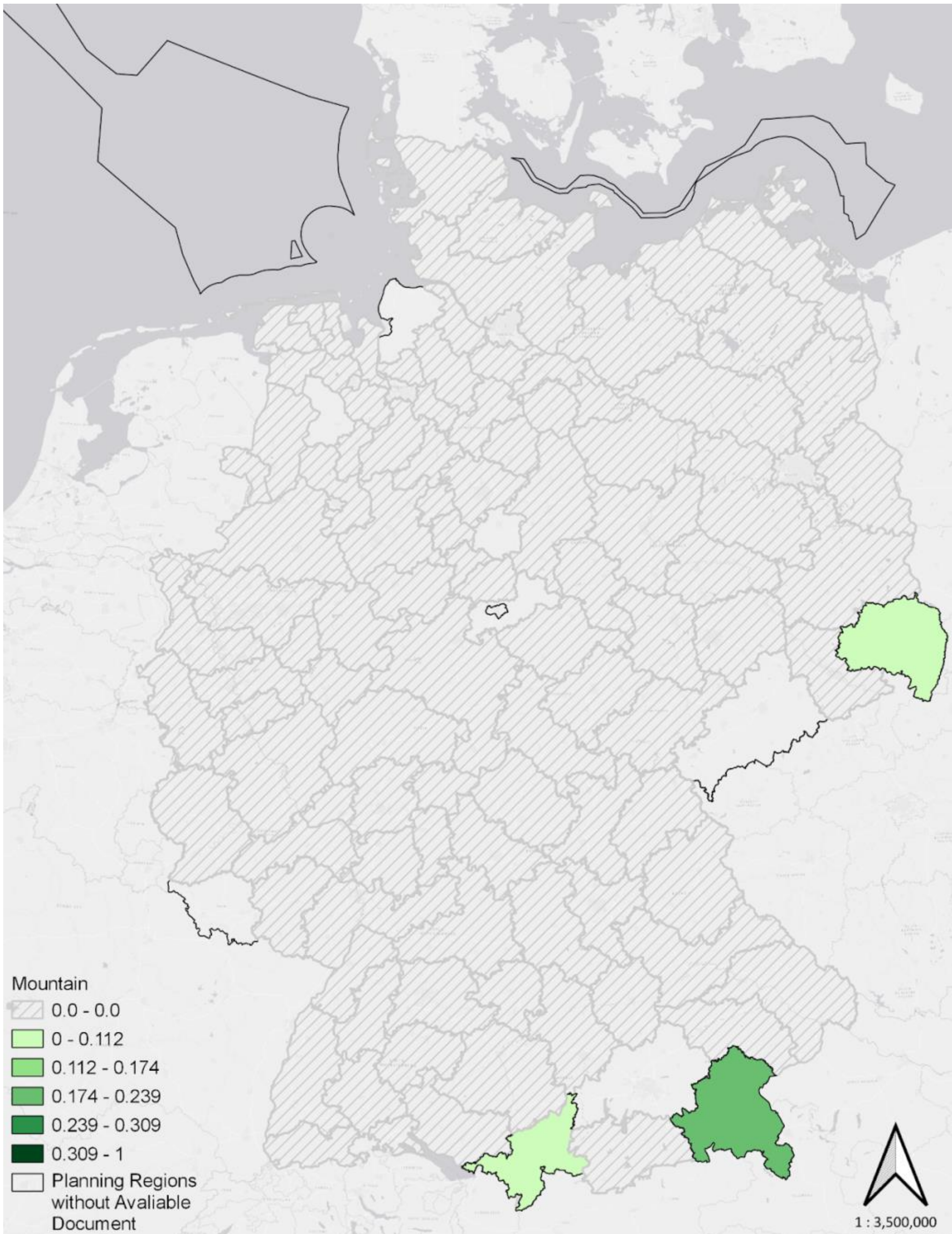

Figure 10: Spatial Distribution - Mountain Area Protection

Similar to Coastal Protection, the spatial planning focus on Mountain Protection also follows regions with significant continuous terrain, primarily the Alps in Bavaria and various Mittelgebirge ranges, including the Ore Mountains (Erzgebirge) and the Black Forest (Schwarzwald). However, within these relevant regions, the visualization suggests that explicit, standalone planning designations specifically for "Mountain Protection", defined as natural hazard preventions (erosions, landslides), are relatively rare. Protective functions are oftenly addressed indirectly through broader thematic planning for 1. Habitats, 2. Tourism, or 3. Forests, which are also illustrated in their positive correlations in the Graph *Internal Relationship Between the Climate Topics*. For example, the Bavarian Alpenplan addresses potential natural hazards in mountain areas like erosion and avalanches through tourism infrastructure regulations. 43% of the Bavarian Alps, designated as "rest area" (*Ruhezone*), prohibit further construction of cable cars, ski slopes, and roads. However, such comprehensive instruments are not universally adopted across all German regions. According to the most recent examination of legally binding textual goals (*Ziele*), only 5 of the 32 relevant mountain regions specifically addressed mountain protection aspects, mostly limited to natural hazards (Dosch, 2025). This tendency to include mountain-specific issues under other planning categories likely contributes to the above underrepresentation of Mountain Protection in the spatial density analysis.

Consequently, this limited and often indirect representation in planning documents restricts the potential for robust statistical correlations with real-world indicators.

Heat

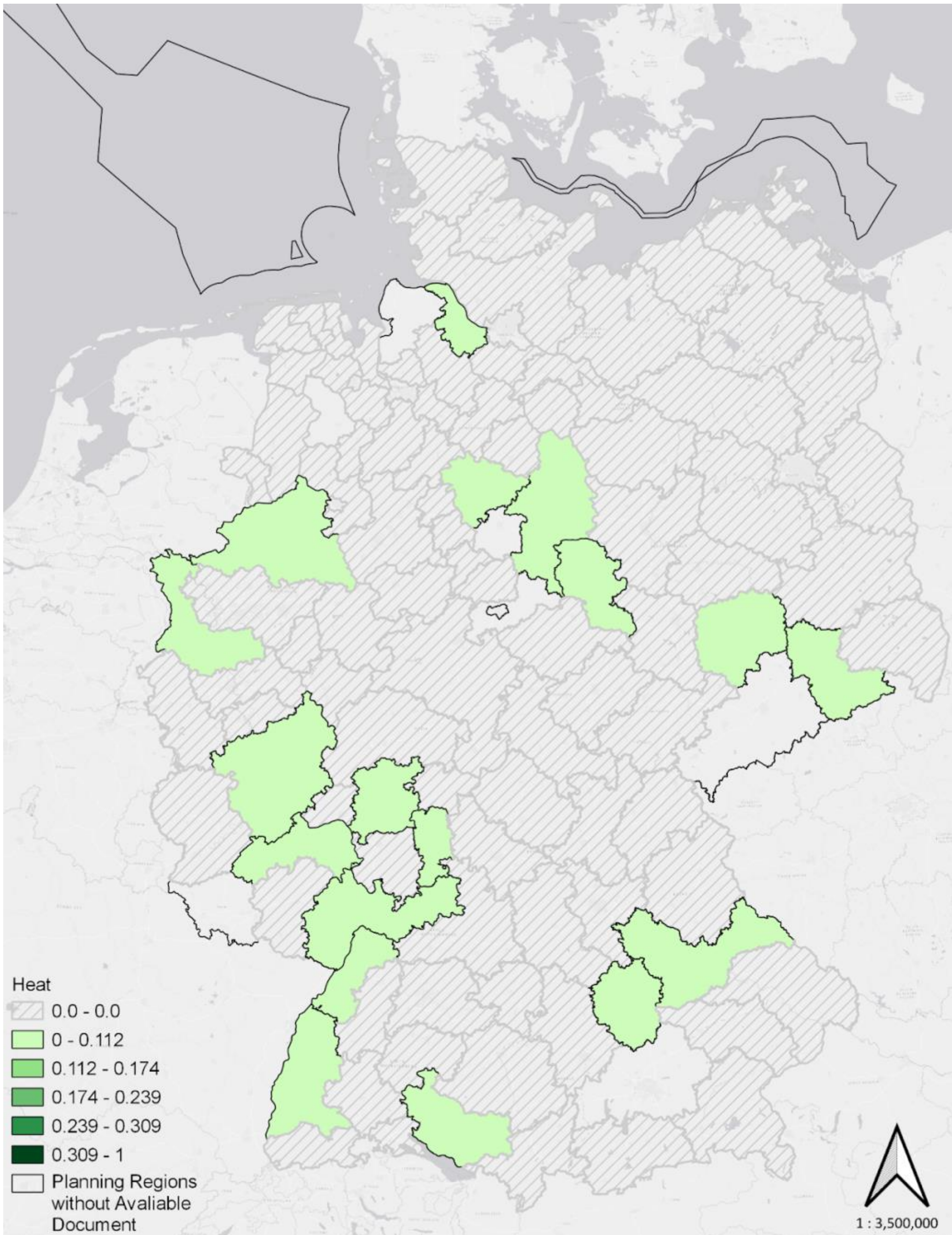

Figure 11: Spatial Distribution – Heat

The spatial distribution of heat mitigation strategies within German regional planning documents indicates a noticeable, though not intensely emphasized, focus on urbanized and densely populated areas. This aligns with the internationally recognized phenomenon of exacerbated heat stress and Urban Heat Island (UHI) effects prevalent in cities. While most state development plans contain textual provisions - including green infrastructure, cold air corridors, and water body creations - the binding designations at the regional level remain limited.

Geographically, the observed planning focus in parts of central and southern Germany aligns with areas identified as having higher heat exposure. According to the DWD Climate Data Center in 2022, significant increase in “Hot Days” are observed in the above colored regions, particularly in Brandenburg and Southern Germany along major river valleys like the Rhine, Main, and Danube. These lower-altitude areas are inherently more vulnerable to heat accumulation compared to higher-altitude regions like the Alps or Black Forest.

The correlation matrix findings, indicating a positive association between heat mitigation planning emphasis and population/settlement density, demonstrate the risk-directed nature of this topic. To provide climatic relief and recreational space for a large population, spatial instruments like regional green belts are strategically designated around major urban centers, where human vulnerability and the potential for UHI effects are highest. However, the overall implementation and emphasis, especially via regional-level, binding spatial designations, is significantly underdeveloped.

Water Shortage

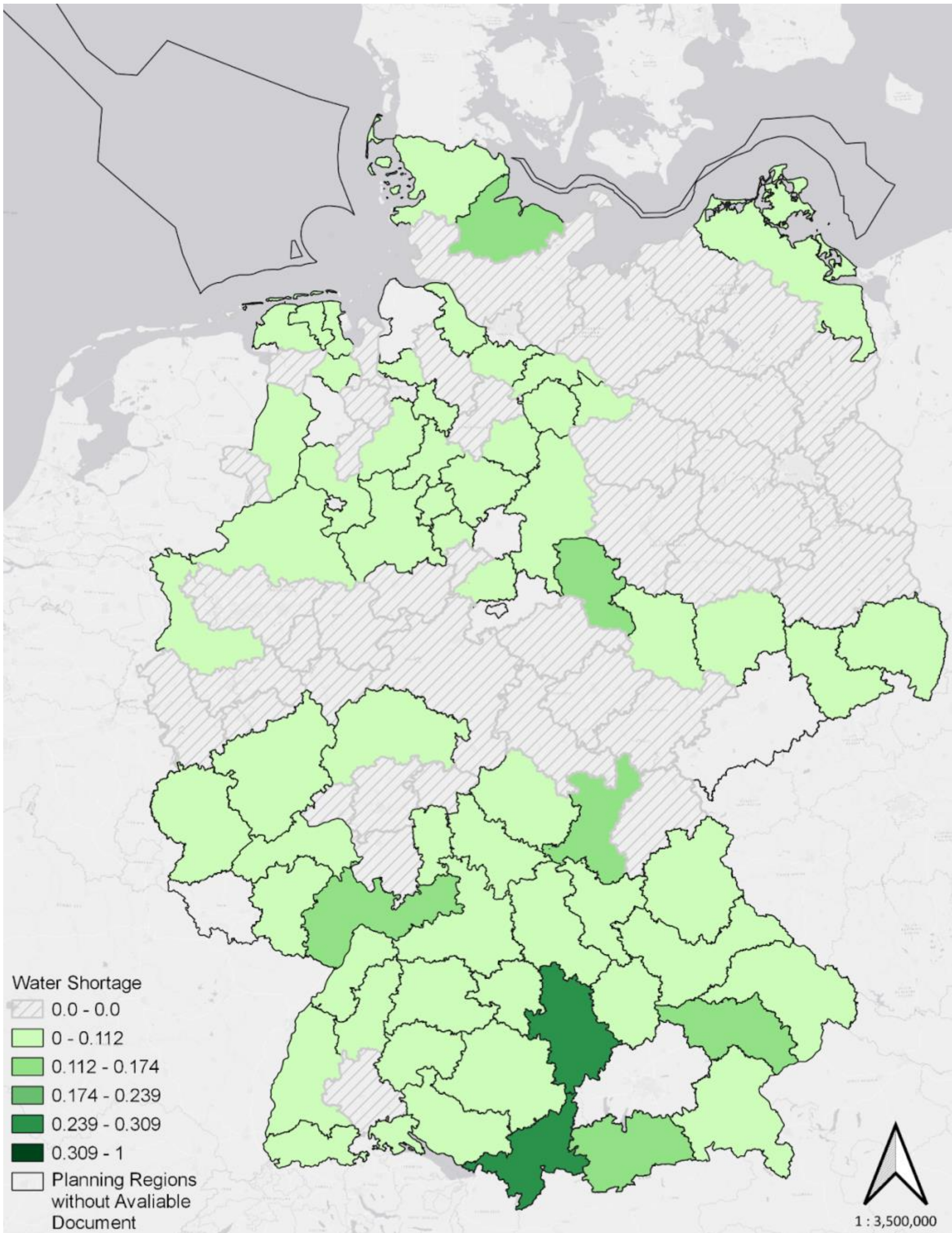

Figure 12: Spatial Distribution - Water Shortage

The spatial distribution of Water Shortage mitigation measures reveals an emphasis in areas with lower precipitation and higher potential evapotranspiration, including Southern Germany, Rhine-Hesse, the northern Upper Rhine Graben, and the Lower Main River plain.

The water scarcity is particularly acute in metropolitan areas like Frankfurt, with a historically heightened water stress caused by their industrialized nature and population density. Drinking water are mainly imported from the Hessian Ried and Vogelsberg regions, putting pressure on the local groundwater reserves. However, the implementation of mitigation strategies, for example, reserve areas for ground and surface water protection, does not perfectly align with the identified “dry regions”. Brandenburg, despite its potential vulnerability, shows a notable gap in such implementation. This suggests potential factors on planning prioritization beyond immediate climatic dryness. The relatively lower emphasis in some northern areas might relate more to historically sufficient water availability with a uniformly wetter climate.

The observed positive correlations between water shortage planning and the Secondary Sector, Settlement Density, GDP per inhabitant, and Percentage of Foreign Guests suggest a linkage between water demand and socio-economic activities. Urbanized and industrialized regions inherently generate higher water demand for domestic supply, industrial processes, and potentially tourism, intensifying competition for resources, especially during dry periods. This is exemplified by the growing pressure on water resources in metropolitan areas like Frankfurt. The negative correlation with water area might suggest that regions with large surface water bodies focus less on scarcity prevention compared to other water-related topics like flood management. Overall, climate vulnerability is considered not the only factor in shaping the planning landscape for water management, as existing settlement structure, economic activity, and the resulting water demand strongly modulate the incorporation of mitigation strategies in the planning documents.

Tourism

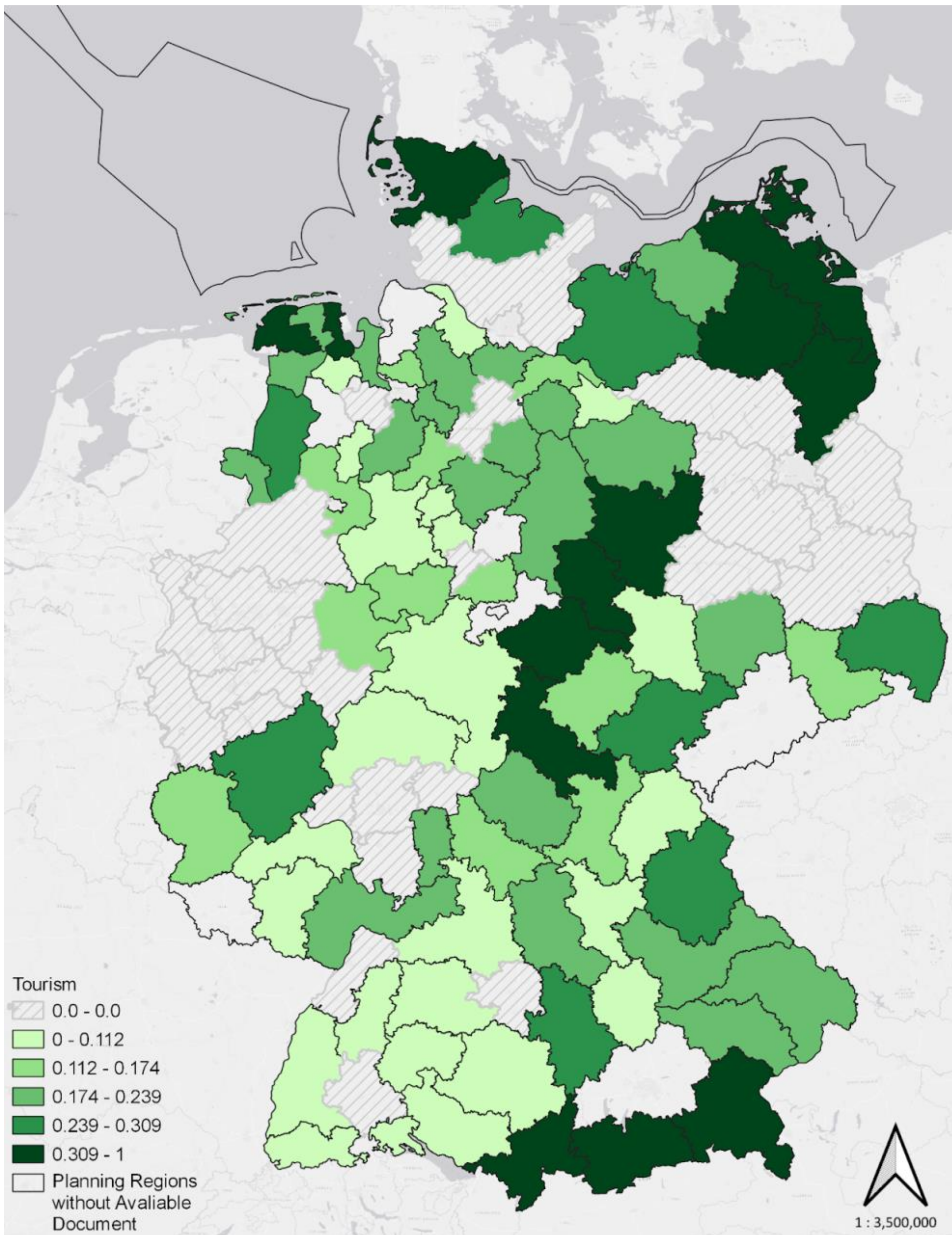

Figure 13: Spatial Distribution - Tourism

The spatial distribution of climate tourism planning aligns logically with Germany's primary tourism resources. A focus is identifiable in northern coastal areas (Schleswig-

Holstein and Mecklenburg-Western Pomerania), southern mountain regions like the Alps, and parts of central Germany known for cultural heritage or specific natural landscapes. Climate change, including global warming and natural disasters with increased frequency, is anticipated to put pressure on German coastal and mountain destinations. Thus, the high awareness level across regions illustrates the forward-looking spatial planning in Germany.

The positive correlation between tourism planning emphasis and indicators including Tourism Density and Accommodation Capacity suggests that current interventions often respond to, and aim to manage, existing tourism intensity. The correlation with Water Area, rurality, per inhabitant recreational area, and the primary sector likely reflects the planning challenges in regions where nature-based tourism (coastal, lake, or rural landscapes) intersects with agricultural activities and requires careful management of natural resources and potential land use conflicts. This aligns with the federal suggestions of implementing sustainable tourism, eco-tourism, or agri-tourism to balance between negative impacts on and economic opportunities of these natural and agricultural assets (Dosch, 2025).

Conversely, there a less emphasis on tourism planning in major urban centers or international hubs like the Rhine Valley, despite high visitor numbers (including international tourists) are observed. These destinations often rely more heavily on cultural attractions, events, business travel, and extensive existing transport and accommodation infrastructure rather than specific natural landscape features managed through regional spatial plans. While urban planning in these areas might address tourism needs through infrastructure planning or zoning, its possible that this analysis, with a specific focus on managing natural resources for sustainable/environmental tourism, might overlook these regional planning instruments that might contribute indirectly to environmental protection.

Habitats

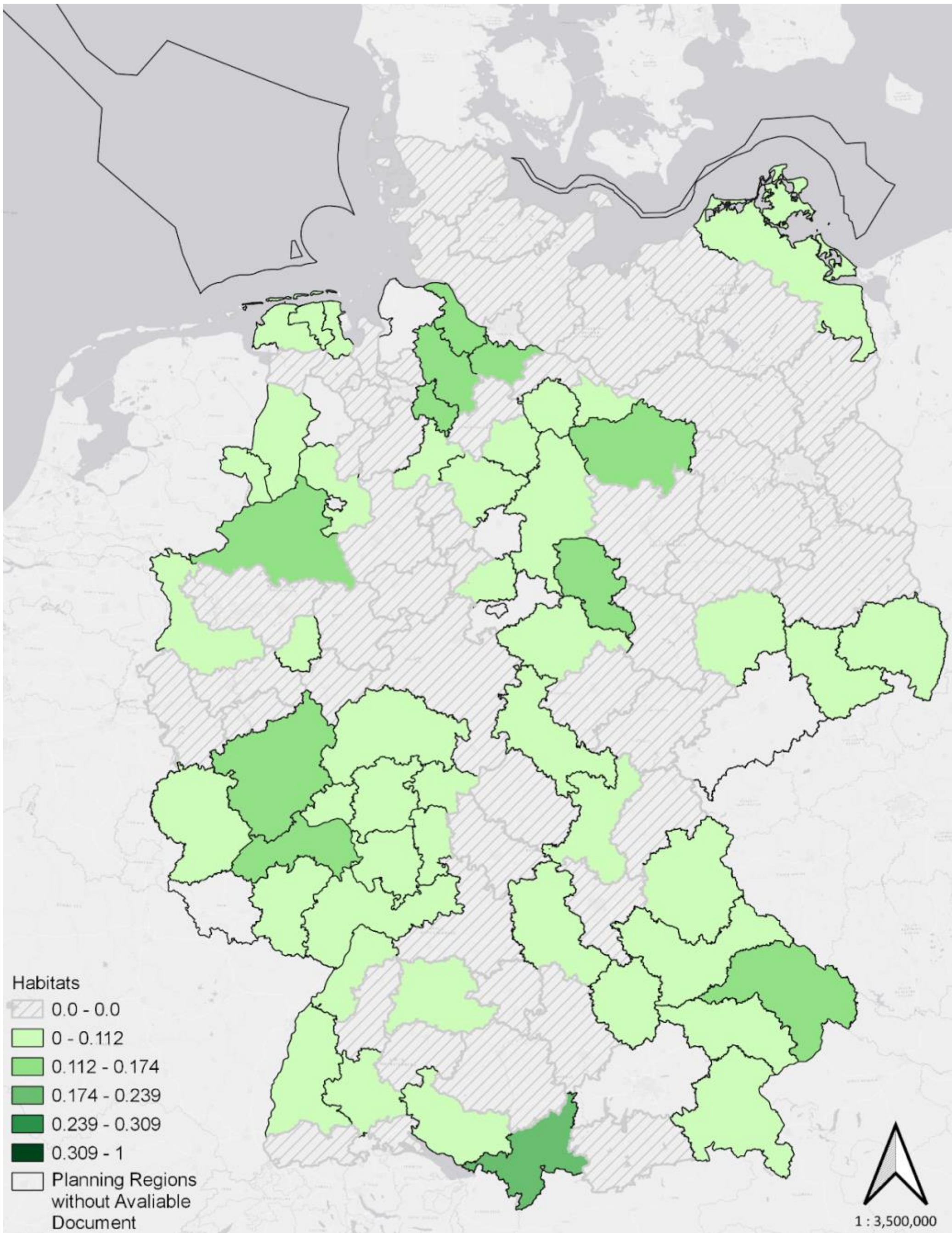

Figure 14: Spatial Distribution - Habitats

The spatial planning emphasis on Habitat Protection is moderately applied with average intensity. A core element of habitat protection within German spatial planning is the development of an interconnected habitat network, mandated by federal law (§ 20

BNatSchG, § 2 Abs. 2 Nr. 6 ROG) to facilitate species migration and maintain biodiversity. The observation of particular emphasis in southern and central Germany might relate to the presence of ecologically valuable areas like the Alps and Mittelgebirge ranges.

Regarding the correlations, the weak positive association with the Secondary Sector, GDP, and foreign guests is complex. It might suggest that in economically developed regions, habitat protection is integrated as a compensatory measure or as part of maintaining high-quality landscapes that attract investment and tourism. However, this topic is framed mostly as an environmental objective at the national level, which should be considered conflicting with economic development, particularly energy infrastructure. The weak negative correlation with recreational and water areas seems counterintuitive, as these often overlap with protected habitats. This might also reflect regional trade-offs.

Similarly, Habitat protection planning inherently interacts with other planning domains. Most notably, the expansion of renewable energy infrastructure (wind turbines, solar farms, power lines) creates significant land-use conflicts with habitat conservation. Other climate adaptation measure, such as river restoration, flood protection, or forest conservation, might have synergies but also potential conflicts with existing habitat structures. After all, spatial planning has limited legal power to dictate the intensity of agricultural or forestry activities in the regions, leading to only a moderate emphasis on habitat protection.

Heavy Rain

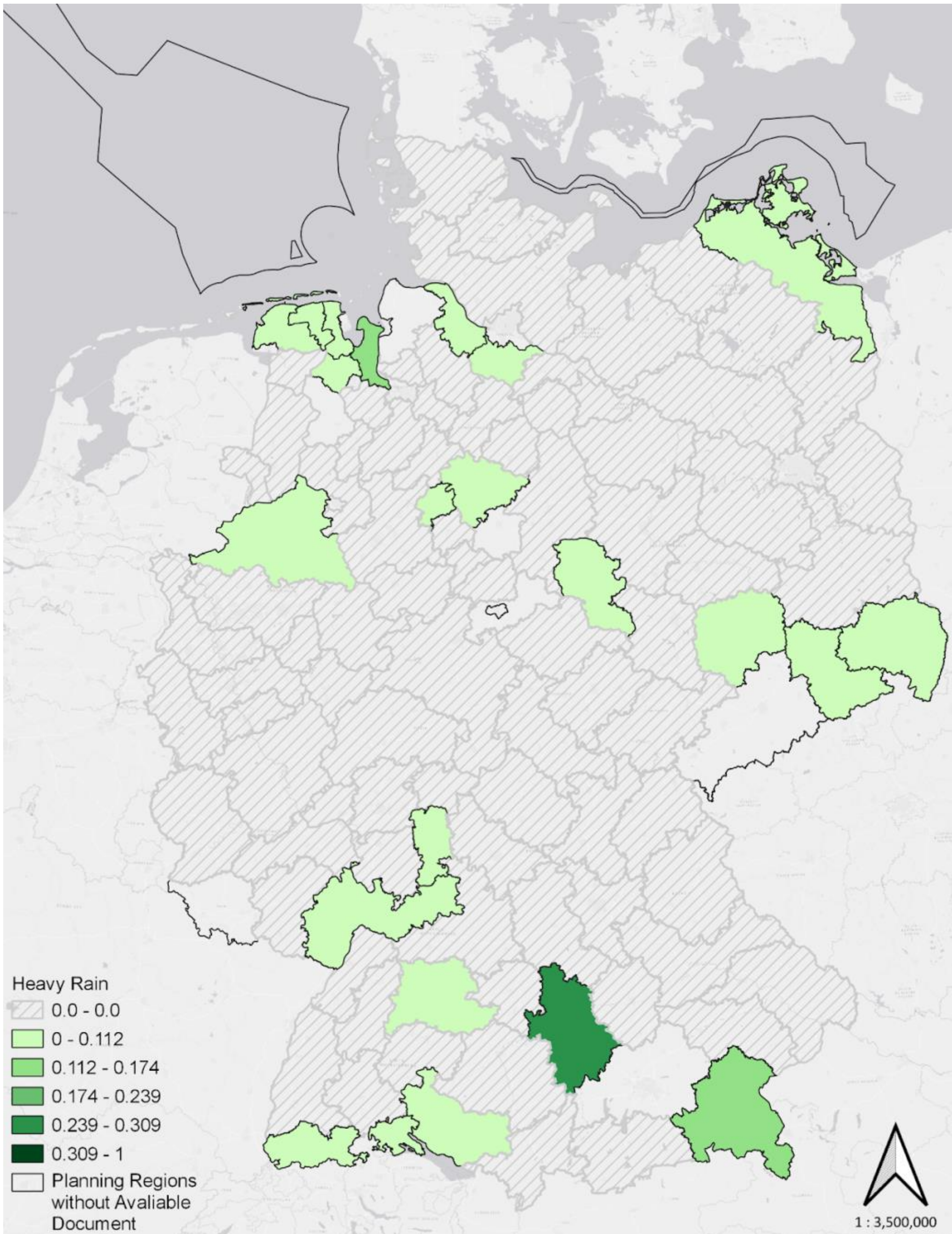

Figure 15: Spatial Distribution - Heavy Rain

The explicit integration of mitigation strategies specifically targeting heavy rain events within German regional planning documents appears relatively scattered and underdeveloped compared to traditional riverine or coastal flood protection. Confirmed in an empirical study, only 9 out of 116 analyzed planning regions included heavy rain management as a binding goal or principle as of 2023. Only certain southern and central regions, potentially those with heightened environmental awareness or specific vulnerabilities (i.e. topography prone to flash floods), and northern coastal areas face intense rainfall associated with storms, have shown a greater attention. It's evident that there's a current lack of a widespread, systematic planning approach targeting heavy rain in the current generation of regional plans.

While heavy rain mitigation strategies have potential overlap with Flood Protection and Coastal Protection Planning, the extreme weather event's unique outcomes, for example, localized flash floods and overloading urban drainage systems, differ from the slower-onset dynamics of large river floods or coastal storm surges. These unique characteristics require specific management approaches at the local or catchment level, which are absent in the current planning scheme.

The observed positive correlation with Mountain Protection aligns with the identification of heightened risk of erosion and landslides in steep terrain, as detailed in the federal level guideline. The correlation with Water Shortage mitigation might reflect integrated water resource management strategies, i.e., capturing and managing intense rainfall as water resource augmentation or groundwater recharge improvements.

Regarding other social indicators, the modest positive relationship with recyclables could suggest that regions with comprehensive sustainability strategies incorporate heavy rain management alongside other progressive environmental policies. The positive linkage with settlement density is more relevant, as urbanized areas face amplified risks due to high proportions of impervious surfaces lead to concentrated runoff and increased risk of property damage. Existing planning instruments logically include urban drainage infrastructure, surface water management, or potentially green infrastructure solutions like bioswales and green roofs.

Forest Protection

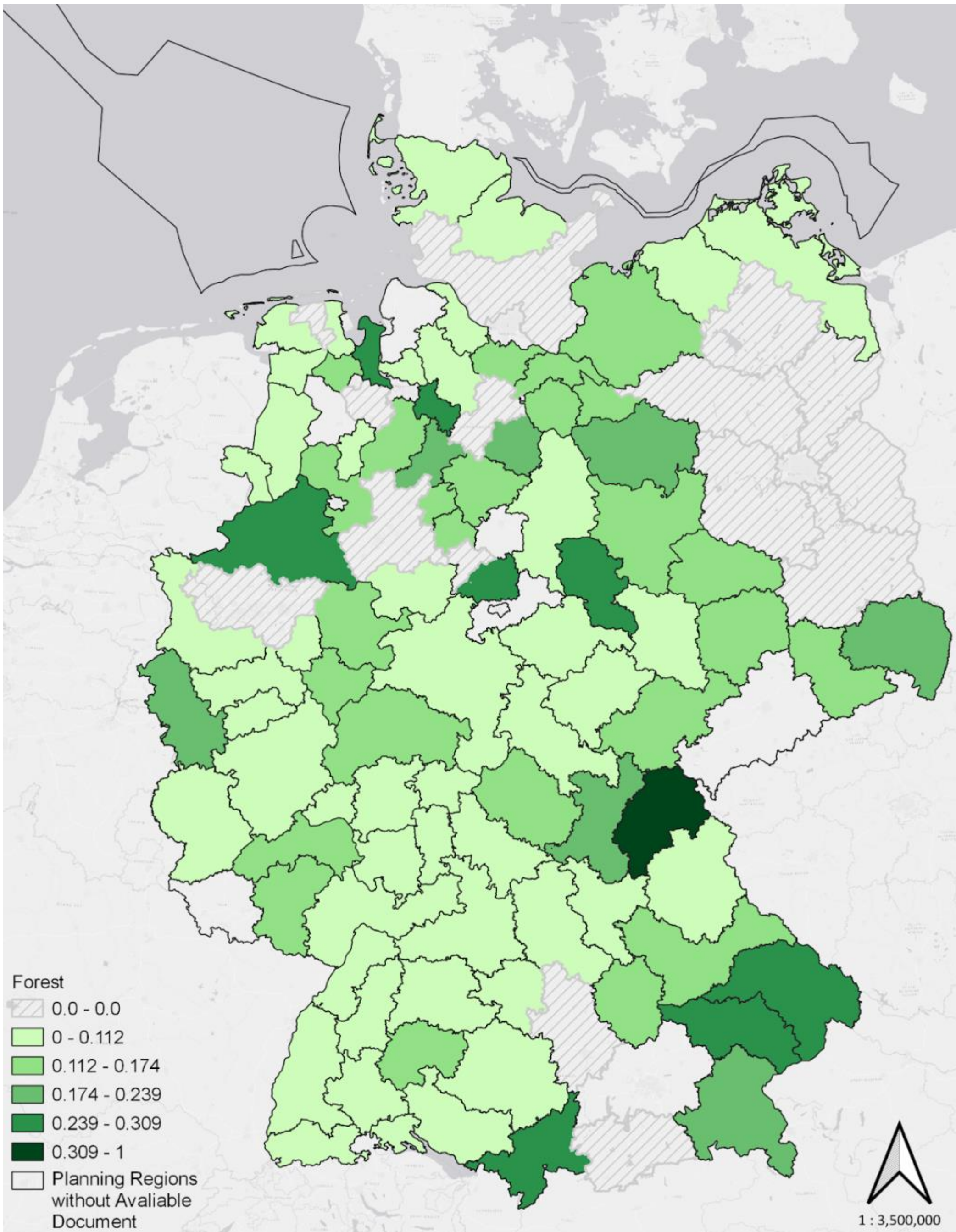

Figure 16: Spatial Distribution - Forest Protection

Forest Protection Policy shows a uniform distribution across Germany, with a geographical alignment with forested and rural landscapes. While designations related to forestry exist in approximately 75% of planning regions, specific instruments as well as their intensity vary considerably across states. Nationally, the coverage of forestry designation zones is currently modest, encompassing 9.3% of the land areas as priority and reserve areas (Dosch, 2025). While forests are implicitly protected under broader nature conservation designations, explicit spatial planning at the regional level is not uniformly applied. For instance, in Schleswig-Holstein, which has the lowest forest coverage in Germany, no binding laws specify priority and reserved areas for forest expansion. In contrast, in Saxony, Thuringia, Rhineland-Palatinate, and Hesse, priority and reserved areas are designated for forestry.

The modest positive correlations observed with the secondary sector, rurality, and forest area likely reflect planning activity where forestry is an important economic factor or where forests require explicit protection from competing land uses like industrial development or settlement expansion in rural settings. However, it's worth noting that in regions with sparse forests, such as West Saxony, spatial planning instruments are also adopted to create areas for afforestation. This might explain forest protection emphasis' weaker correlation with forest area. The negative correlation with water area and tourism indicators might suggest that in regions where water landscapes or tourism are dominant economic or planning drivers, the explicit designation of areas solely for forestry purposes receives less priority compared to water resource management or the protection of landscapes for recreational value.

Again, similar to other sector-specific topics, while regional plans can designate land uses for forestry preservation and expansion, they lack the legal competence and technical details in regulating private landowners' management practices like climate-resilient forest conversion (Bauhus et al., 2021; Dosch, 2025). The uniform mentions of climate-adapted forestry in plans are typically in the form of non-binding principles, limiting the forest's functions as carbon sinks or biodiversity reservoirs.

Chapter 5. Discussion

Policy Suggestions

The ambitious goals of a rapid energy transition and escalating climate challenges in Germany, in comparison to the uneven and limited distribution of emphasis in planning documents illustrated above, demand a fundamental strengthening and adaptation of the current spatial planning system. The German spatial planning system, known for its comprehensive, hierarchical, and legally embedded nature, leads to a top-down approach for higher uniformity and legal certainty. The robust review and supervision mechanisms, with elements of bottom-up feedback, allows for flexibility within compliance. However, the strong emphasis on thoroughness and coordination inevitably leads to complex processes without public participation, resulting in potential implementation gaps at the local level. While spatial planning authorities are increasingly aware of and engaging with current issues, significant deficits remain in terms of strategic clarity, data integration, local regulations, and multi-level governance coherence/efficiency. This chapter discusses key areas for improvement identified in the German context - the evidence base, strategic directions, and multi-level coordination - drawing insights from both the spatial analysis and international practices to provide actionable policy recommendations.

1. Strengthening the Foundation: Improving the Data and Evidence Base for Planning

The cornerstone of effective spatial planning and implementation is reliable, accessible, and actionable evidence base. The German system, while with established general data monitoring and sharing platforms like the Raumordnungsplan-Monitor

(ROPLAMO), faces challenges in integrating statistic- and report-based assessments into statutory planning processes. Currently, ROPLAMO as the nationwide planning information system, records spatial and textual specifications at both state and regional levels (BBSR, n.d.). Together with INKAR, the interactive online atlas for urban development, researchers are able to deliver comparative studies like this thesis to assess the quality and effectiveness of current spatial plans (BBSR, 2024). However, more climate-specific statistics, for example cutting-edge climate science and their adaptations, regional vulnerability assessments, and energy system modeling, are still hidden behind reports produced by different actors (network operators, energy agencies, planning authorities, etc.) with significant access and language barriers.

International best practices demonstrate the value of Spatial Data Infrastructures (SDIs) and Decision Support Systems (DSS) that integrate diverse datasets, including the aforementioned topics ranging from climate projections, socio-economic vulnerabilities, ecological sensitivities, infrastructure networks, and energy potentials – into user-friendly platforms for planners and the general public. In the European context, the Netherlands and the UK have invested heavily in national climate information portals and risk assessment frameworks (e.g., UK Climate Change Risk Assessment - CCRA) that directly inform spatial policy and adaptation planning.

Possible policy suggestions under this topic include:

a. **the enhancement of current data infrastructure to promote its monitoring capabilities and promote open data access.** While valuable tools like KlimREG have emerged from research efforts by BBSR, little to no applications across planning authorities are observed in this study. It is crucial for the federal to disclose high-resolution climate impact data through publicly accessible platforms with toolsets for scenario analysis and visualization, instead of through individual study reports that have limited exposure and impact. Federal planning authorities should also consider expanding the capabilities of current platforms, i.e. ROPLAMO, beyond tracking designations to include monitoring the outcomes of planning decisions related to climate goals. This measurement completes the feedback circle for the higher-level authorities to assess the effectiveness of their guidelines and goals published through national-level legislative documents, i.e. ROG.

b. **Mandate standardized Vulnerability and risk assessments and the incorporation of these frameworks at the local level.** In addition to Federal-led information collection and disclosure, it's recommended to require State and Regions to conduct regular, standardized climate risk and outcome assessments using common methodologies, feeding directly back to the aforementioned data platform for spatial plan reviews and adaptation strategy development.

2. Defining Direction: Developing Measurable Targets

In contrast with the increasingly quantified goals at federal level (energy transition goals, greenhouse gas emission reduction goals, percentage of reserve areas, etc.), specific and measurable are relatively uncommon in local-level spatial planning documents. The mechanism of regional planning authorities - translating general objectives into actionable, monitorable targets that guide land use decisions, fails.

In the German context, the newly promulgated Climate Adaptation Act (*Klimaanpassungsgesetz*, KAnG) in 2023 is a crucial legislative action to rectify this by mandating measurable goals at both the federal and state levels. International experience highlights the effectiveness of such target-setting at local levels. Cities like Copenhagen and Rotterdam have integrated quantitative targets for green infrastructure (e.g., square meters of green roofs, water retention capacity) into their climate adaptation plans and urban planning regulations.

Specific integration approach includes:

a. **Mandatory translation of risks into targets**: Adaptation and mitigation strategies in regional spatial plans should move beyond identifying risks to normative statements about desired outcomes in actionable spatial terms. While topics closely linked to direct land use, for example, energy transition and mountain protection, have quantifiable goals, other topics lack measurable objectives. Instead of simply citing the aim of "improve flood protection" from federal guidelines, local spatial designations should be embedded with binding goals (Ziele) in terms like "designate and secure an additional X hectares of functional flood retention area in vulnerable catchments by 2035" or "ensure all new developments in identified heat-risk zones incorporate specific green infrastructure standards exceeding Y% site coverage."

b. **Innovation and Flexibility in climate adaptation should also be considered.** Recognizing the uncertainties involved, adaptation targets should be periodically reviewed and adjusted based on local monitoring results and national climate projections. The flexibility embedded in ROG, which allows reasonable regional deviation of LEPs, contributes to the establishment of such adaptive management cycle within the planning system. Planning authorities should also consider pilot programs like Demonstration Projects of Spatial Planning (*Modellvorhaben der Raumordnung*, MORO) to explore and evaluate innovative spatial planning instruments.

3. Enhancing Multi-level Coordination and Collaboration

As discussed in the literature review chapter, the effectiveness of spatial planning is fundamentally dependent on robust coordination across multiple levels of governance (Federal, State, Planning Regions) and sectoral policies (energy, tourism, nature conservation, agriculture, etc.). Germany's federal system presents inherent coordination and effectiveness challenges, leading to policy and adaptation inconsistencies, implementation delays, and uncoordinated approaches. In topics like energy transition and coastal protection, significant difficulties and inefficiencies arise when coordinating transboundary strategies or aligning regional strategic guidance with local land-use decisions.

In Germany, existing mechanisms like the MKRO/RMK provide a platform for interstate coordination, while federal plans like the Federal Spatial Development Plan for Flood Protection (*Bundesraumordnungsplan Hochwasserschutzm*, BRPH) establish a toolset for setting nationwide standards. These projects assist inter-regional learning, allowing the coordination of shared infrastructure like heat networks and air corridors (Dosch, 2025). However, it's still essential to strengthen and promote these mechanisms to overcome the existing coordination gaps.

a. The federal government should **Mandate Cross-Border Consultation and Planning** for inter-municipal issues (infrastructure corridors, river and coastal management, habitat chain networks). A formal consultation leads to joint planning processes between adjacent planning authorities, which ensures mutual consideration and alignment of objectives. Such coordination might also encourage planning based on functional regions (energy regions, metropolitan areas, mountain ranges), taking into account local advantages transcending traditional administrative boundaries.
b. Within regions, local planning should **Formalize Links between Spatial and Sectoral Planning**. As the mitigation strategies are inherently intercorrelated, improving the legal and procedural integration between spatial planning (climate goals) and sectoral planning (i.e., energy network development plans (NEP), water management plans) leads to mutual benefits with minimized conflicts.

In conclusion, achieving such transformation not only requires legislative adjustment or institutional reforms, but mainly requires a sustained commitment to foster a collaboration culture. It's only through innovative planning tools and schemes can human fit for the complexities of the 21st century.

Reviewing Methodology: Advantages, Limitations, Ethical Considerations, and Further Research

This section critically evaluates the Large Language Model (LLM)-based content analysis methodology employed in this thesis to analyze climate adaptation strategies within German regional planning documents. It considers the observed theoretical advantages and limitations of the approach, discusses relevant ethical considerations, and outlines potential directions for future research building upon this and similar work.

Advantages and Limitations of the LLM Approach

Regional planning documents, often numerous and extensive, making manual qualitative analysis across a broad geographic scope - the entire nation in this case - exceptionally time-consuming and labor intensive. The LLM methodology dramatically improved efficiency, allowing for the current systematic processing and comprehensive overview of climate strategies across planning regions. This efficiency is not merely a time, as the employed workflow allows future recursive analysis on additional documents with improved consistency and reduced cost. Manual coding, especially when conducted by multiple researchers and over extended periods, is inherently susceptible to variability and subjective interpretation. By applying a defined set of prompts and a consistent analysis model, the LLM approach offers a higher degree of consistency over time and across all documents, which is particularly valuable for comparative analysis across diverse regional plans and for longitudinal studies.

Despite the advantages, the specific methodology design and application within this research also introduce several limitations. LLM methods are inherently sensitive to prompt engineering, that the quality, relevance, and accuracy of the analysis are highly dependent on the specific prompts used to query the LLM. In addition, the internal reasoning process of the LLM remains largely opaque, making it difficult for us to fully trace how and why a certain classification or interpretation was made, known as the "black box" challenge. Specific to this research, firstly, the analytical framework relies on certain underlying assumptions regarding the selected corpus of German regional planning documents. These include assumptions about the representativeness of the chosen documents in reflecting the broader landscape of regional climate planning in Germany, assuming that more mentions of certain topics correlates with more efforts in such mitigation strategy; we also assume that the extent to which the formal language and terminology used within these texts are consistently and comprehensively interpretable by the LLM, in alignment with their intended planning meaning. The study implicitly assumes that the textual characteristics captured by the LLM sufficiently represent the conceptual core of the adaptation strategies discussed, which leads to potential deviation from the empirical studies and the ground truth.

Secondly, a significant constraint is the discrepancy between analyzing documented strategies and inferring their real-world implementation or effectiveness. This research only examines the presence, nature, and emphasis of climate strategies as articulated within the planning texts. The absence of a publicly available climate risk and outcome dataset hinders the measurement of the degree to which these documented intentions translate into tangible action, receive adequate funding, or achieve desired climate resilience goals. The "text-vs-reality" gap remains a critical limitation, as the observed textual emphasis does not necessarily correlate with more robust or actionable implementation on the ground.

Thirdly, the methodology that characterizes the density or prevalence of climate themes, differs from exhaustive qualitative analysis. While LLM moves “beyond keywords” to categorize strategies, the study did not achieve a context-rich understanding of each individual plan that could be derived from intensive, human-led qualitative case studies. In the validation process, we are heavily reliant on our project partners’ input about individual narrative and highly localized contextual factors that are abstracted and generalized while analyzing using LLMs.

With that being said, while efforts were made to validate the LLM’s analytical outputs through multiple avenues - including alignment with existing empirical studies on climate adaptation planning, insights derived from field knowledge, and targeted manual validation of selected documents - inherent limitations in this validation process persist. The scope of direct manual verification is minimal considering the entire analyzed corpus. While external empirical studies and field knowledge provide valuable contextual benchmarks, their direct applicability for confirming the accuracy is not absolute.

Future Research Directions

The findings and methodological discussions of this thesis suggest several promising directions for future research. These potential research questions that are not fully explored within the scope of this thesis, could refine the analytical tools, deepen the understanding of planning documents, and explore the relationship between the complex governance structure and climate strategy adaptation.

For enhancing LLM accuracy, future work should consider the nuanced domain of spatial and environmental planning, both through targeted fine-tuning and developing robust, contextualized validation workflows. Training LLMs on corpora composed of German and EU planning documents, climate adaptation literature, and legal text would equip models with a deeper understanding of domain-specific terminology, conceptual relationships, and the unique context of the German planning system. In addition to general LLM benchmarks or manual validation used in this study, future research could explore domain-specific validation frameworks. This includes creating standardized test datasets of annotated planning documents, developing metrics that capture the accuracy of identifying and interpreting complex planning strategies beyond keywords, and incorporating expert review leveraging local partnerships.

Building upon the LLM's capacity for broad thematic identification, a critical next step is to conduct more qualitative investigations into the substance and actionability of plan content. LLMs could assist in initial coding or the identification of widely recognized fundamental metrics in measuring the quality of spatial plans, such as "Scientific Bases," "Regional Cooperation," "Inclusiveness," and "Public Participation" (Connell & Daoust-Filiatrault, 2017; Lyles & Stevens, 2014). Assessing qualitative metrics, such as the clarity of objectives, the proposed mechanisms for monitoring and evaluation, or the specificity of proposed actions, can help better understand the current state of climate planning, as well as potential fields for improvement.

To bridge the gap between documented strategies and their real-world implications, future research could also focus on the empirical relationship between plan characteristics and climate adaptation outcomes. For example, connecting LLM-derived qualitative and quantitative data on the density, clarity, and inclusiveness of adaptation strategies to spatio-temporal datasets on climate risks, experienced climate-related damages, and indicators of implementation success. While this would require significant effort in addressing current deficiencies in data monitoring, collection, and distribution, it helps investigate causal dynamics behind the observed nuances in this study: **Do experiences of significant climate-related risks and damages act as a primary driver for the subsequent development and implementation of more robust adaptation strategies (i.e. a reactive model)** or conversely, **does heightened awareness, proactive strategizing, high resource availability, and comprehensive planning (as reflected in plan content) prevent or mitigate such damages from climate-related statistics (a proactive, preventative model)?** Furthermore, climate adaptation planning is inherently a multi-level governance challenge, and future research could examine the interplay between national/federal directives and local/regional agencies in shaping the effectiveness of climate adaptation strategies. This could involve an assessment of bureaucratic efficiency vs. strategic alignment, whether federal efforts that ensure coordination and consistency lead to more effective and synergistic outcomes across regions, or if such top-down approaches introduce bureaucratic obstacles, limited local innovation, or result in “one-size-fits-all” plans that often lead to poorly implemented plans regarding nuanced local contexts and vulnerabilities. Collectively, these potential research questions not only advance the methodological tools for analyzing complex policy documents but also enhance practitioners’ substantive understanding of how effective planning could be designed, implemented, and governed in different planning contexts.

Chapter 6. Conclusion

This thesis serves as an exploration of contemporary climate adaptation strategies within German regional planning documents, employing the currently innovating LLM-based content analysis. Moving “beyond keywords”, the research aims to develop and assess a computational methodology capable of capturing the nuanced and complex planning schemes in policy documents, in light of the escalating need for more effective planning responses to the heightened climate issues. The study successfully demonstrated the considerable advantages of an LLM-driven approach over manual methods for analyzing extensive and complex textual data inherent in planning documents. The methodological findings underscore the LLM’s capability in understanding semantic context, gains in scalability and efficiency, improved consistency in analysis results, and the potential for discovering latent thematic emphases that might otherwise be overlooked in traditional evaluation frameworks. This methodological advancement itself represents a primary contribution, offering an experimental trial for utilizing cutting-edge toolsets like AI to support planning research and practice.

On the other hand, the findings regarding the content of German regional adaptation plans elaborated in the preceding chapters confirm empirical studies and also reveal interesting patterns that contribute to practitioners. The high level of attention for certain national topics, particularly Energy Supply and Flood protection, is driven by robust federal legislation and mandates, while more evolutionary topics like Carbon Sink and Heat Mitigation are only observed in urbanized areas with higher public awareness and resource availability. These insights directly informed the policy recommendations presented, that while the current top-down planning system outlines robust action plans and goals, emphasis on multi-level and cross-border cooperation is required to overcome existing coordination gaps. Such measures, supported by innovative planning tools and practices, are crucial for addressing the fast-changing challenges that vary across geographic regions.

In conclusion, the contribution of this research is thus threefold: methodologically, it pioneers an LLM-based workflow for planning document analysis; empirically, it offers insights into the current landscape of documented climate strategies in German regional plans; and practically, it provides evidence-based recommendations for enhancing the efficacy of both strategies and the broader planning process. As Germany and national governments worldwide address the accelerating impacts of climate change, the need for a more robust, adaptive, and well-coordinated planning scheme has never been more urgent. While technology alone could not be the panacea, the thoughtful application of innovative instruments like LLMs can significantly increase our capacity for a more resilient future.

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TECHNICAL APPENDIX A

We used the following code and prompt via ChatGPT API to generate the results for this study. Full data cleaning scripts are available upon request.

```
def get_structured_response(document_content, api_key):
    openai.api_key = api_key

    # Construct the prompt
    prompt = """You now act as an urban planner, and I would like you to evaluate the
predefined topics related to climate strategies from the following text from German Planning
documents. READ THE FULL UPLOADED TEXT as careful as you can, and organize
your answer based on the full content of the plan. For the given plan, return 1. the date of the
plan, 2.whether each strategy is mentioned, and 3. if so, what are the keywords associated
with each strategy. For the returned keywords, only return the exact word from the plan text.
Return, and only return in JSON format:  {\'DATE\': \'2000-01\', \'TOPIC 1\':\'Energy saving
and traffic\',\'MENTIONED\' : \'TRUE\', \'MENTIONED_PAGE\' : \'#PAGE_NUMBER\' ,
\'TOPIC 1 Keywords\' : \'Energieeffizienz, Fahrrad\'\'TOPIC 2\':\'Carbon
Sinks\',\'MENTIONED\' : \'FALSE\', \'MENTIONED_PAGE\' : \'NA\',\'Keywords\' : \'\'}
The TOPICS are provided as below: ### START_OF_TOPICS_AND_EXAMPLES ### {\n
"TOPIC 1": "Energy saving and traffic ",\n  "TOPIC 1 Explaination": "Energy-saving and
traffic-avoiding, integrated settlement and traffic area development",\n  "TOPIC 1
Keywords": "energiesparen, energiesparende Bebauung, energiesparende
Siedlungsentwicklung, Energieeffizienz, Fahrrad, Radverkehr, Öffentlicher
Personenverkehr, Personennahverkehr,Multimodal, intermodal",\n  "TOPIC 2": "Energy
Supply",\n    "TOPIC 2 Explaination": "Spatial precautions for a climate-friendly energy
supply",\n  "TOPIC 2 Keywords": "windenergie, photovoltaik, pv-anlagen, erneuerbare
energie, geothermie, wasserstoff, wasserkraftnutzung, bioenergie",\n  "TOPIC 3": "Carbon
Sinks",\n    "TOPIC 3 Explaination": "Spatial planning protection of CO2 sinks",\n  "TOPIC
3 Keywords": "CO2-Speicherung, CO2-Senken, Kohlenstoffsenke, Wiedervernässung,
Moor, Torferhaltung",\n  "TOPIC 4": "Flood protection",\n    "TOPIC 4 Explaination":
"Preventive flood protection in river basins",\n  "TOPIC 4 Keywords": "Flood zones, areas,
flood protection, flood, water retention, flood-adapted construction, retention",\n  "TOPIC
5": "Coastal protection ",\n    "TOPIC 5 Explaination": "Protecting the coast from the effects
of climate change",\n  "TOPIC 5 Keywords": "Küstenschutz, Meereshochwasser, Steigender
Meeresspiegel, Sturmflut, Deichverstärkung ",\n  "TOPIC 6": "Protection of mountain
areas",\n  "TOPIC 6 Explaination": "Protection of mountain areas",\n  "TOPIC 6
Keywords": "Lawine, Muren, Murgang, Steinschlag, Massenbewegung, Permafrost",\n
"TOPIC 7": "Effects of heat",\n    "TOPIC 7 Explaination": "Protection against the effects of
heat in residential areas (bioclimatic stress areas)",\n  "TOPIC 7 Keywords": "Urbane
Wärmeinsel/ Hitzeinsel,Kaltluft, Kaltluftbahnen, Kaltluftschneisen, Frischluftschneisen,
Hitzebelastung, Stadtgrün, Beschattung, Schwammstadt;",\n  "TOPIC 8": "Water
shortages",\n    "TOPIC 8 Explaination": "Regionale Wasserknappheiten",\n  "TOPIC 8
Keywords": "Grundwasserschutz,Grundwasserentnahme,Dürre,
Trockenheit,Niedrigwasser,angepasste Landwirtschaft/ Bewirtschaftung,Bewässerung",\n
```

```
"TOPIC 9": "Tourism",\n    "TOPIC 9 Explaination": "changes in tourism behavior due to
climate change",\n  "TOPIC 9 Keywords": "Tourismus+Klimawandel",\n  "TOPIC 10":
"Habitats",\n    "TOPIC 10 Explaination": "Displacement of habitats for animals and
plants",\n  "TOPIC 10 Keywords":
"Verbreitungsgebiete,Artenspektrum,Lebensbedingungen,Lebensräume,Zerschneidung,unze
rschnittene Räume,Wildkorridore",\n  "TOPIC 11": "Heavy Rain",\n    "TOPIC 11
Explaination": "Protection against heavy rain events",\n  "TOPIC 11 Keywords":
"Starkregen,Regenwasser,Überflutung, Überschwemmung ",\n  "TOPIC 12": "Forests ",\n
"TOPIC 12 Explaination": "Adaptation of forests to climate change and protection against
forest fires",\n  "TOPIC 12 Keywords":
"Waldumbau,Mischwald,Waldbrandschutz/vorsorge,Brandschutzstreifen,Brandschutz,Laub
holz,Brandbekämpfung,Brandverhütung"}\n  "TOPIC 13": "Inclusiveness",\n    "TOPIC 13
Explaination": "Inclusive urban planning for all social groups and cooperation with the
private sector",\n    "TOPIC 13 Keywords": "Participatory process, stakeholder engagement,
private sector cooperation"\n\n    "TOPIC 14": "Scientific Basis",\n    "TOPIC 14
Explaination": "Scientific basis for climate change adaptation and mitigation measures",\n
"TOPIC 14 Keywords": "Climate models, climate projections, climate scenarios, climate
data, climate change impacts, climate change adaptation, climate change mitigation",\n\n
"TOPIC 15": "Viability and Structure",\n    "TOPIC 15 Explaination": "Viability and
structure of climate change adaptation and mitigation measures",\n    "TOPIC 15
Keywords": "Cost-benefit analysis, feasibility study, implementation plan, monitoring and
evaluation, risk assessment, risk management, financing mechanisms, funding sources,
public-private partnerships, international cooperation"\n\n    "TOPIC 16": "Regional
Cooperation",\n    "TOPIC 16 Explaination": "Regional cooperation, and Federal/Regional
level cooperation",\n    "TOPIC 16 Keywords": "Inter-municipal cooperation, regional
cooperation, cross-border cooperation, federal level cooperation, regional level cooperation,
international cooperation, transnational cooperation"\n   ### END_OF_TOPICS ###"""


    response = openai.chat.completions.create(
        model="gpt-4o",
        messages=[
            {"role": "user", "content": prompt}
        ],
        temperature=0,
        max_tokens=1000,
        top_p=1.0,
        frequency_penalty=0.0,
        presence_penalty=0.0
    )

    return response.choices[0].message['content']


def get_completion(prompt, model = 'gpt-4o'):
```

```
messages = [{"role": "user", "content": prompt}]
response = openai.chat.completions.create(
   model=model,
   messages=messages,
   temperature = 0,
   seed = 913
)
return response.choices[0].message.content
```