Proposing targets and limits to urban sprawl as an urban growth management strategy towards sustainability in Germany

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ABSTRACT

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In an era of rapid urbanization, achieving sustainable urban development has become a critical global concern. Yet many regions continue to suffer from the negative repercussions of urban sprawl. Unlike many other environmental issues, urban sprawl is rarely addressed quantitatively, particularly in terms of proposing concrete solutions. This study aims to bridge that gap by first measuring the extent of urban sprawl across 111 planning regions and 16 federal states in Germany using the Weighted Urban Proliferation (*WUP*) method for the period 1995–2015. It then introduces and analyzes five future scenarios as a framework for proposing targets, limits, and warning values for urban sprawl as a strategy to manage it. The results show that (1) Urban sprawl in Germany increased by 51.67%, rising from 2.207 UPU/m² in 1995 to 3.348 UPU/m² in 2015, 7.2 times faster than the growth in the number of inhabitants and jobs (7.2%); (2) projected population trends (whether growth or decline) have a significant influence on setting reference values and determining the sustainability of future scenarios; (3) despite projected population declines in many regions by 2050, inaction—such as continued increases in land uptake per person, as in Scenario 1—will still lead to higher urban sprawl, which highlights the importance of urban form and extent of built-up area; and (4) strategies focused on densifying built-up areas can significantly reduce urban sprawl and represent a sustainable path forward. These findings and proposed reference values provide a solid foundation for future de-sprawling efforts in regional planning and serve as a quantitative reference framework for urban planners and policymakers.

Keywords: Built-up area, Weighted Urban Proliferation (*WUP*), Densification, Shrinking cities, Future scenarios, Compact cities, Land consumption

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Contribution of Authors

As the first author, I was responsible for the conception and structure of the study, data correction, quantitative calculations, data analysis, interpretation of the results, and the writing of the thesis.

This thesis was supervised by Dr. Jochen Jaeger, who provided guidance on the study design, data analysis, and interpretation of findings, and contributed extensively to manuscript editing and revisions.

Dr. Tobias Krüger and Dr. Martin Behnisch served as co-supervisors. They provided the core datasets used in this study and provided support with data analysis and valuable feedback during data preparation and analysis, particularly regarding the planning context in Germany

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1- Introduction

Over 70% of the world's population will live in cities by 2050 (UN, 2019). In order to accommodate the additional number of humans in urban areas, significant land areas will be converted to urban development. Urban development can occur in different forms. An infamous type of urban growth is sprawl. Although it is hard to clearly define this term, a helpful definition suggests that "urban sprawl is a phenomenon that can be visually perceived in the landscape. A landscape suffers from urban sprawl if it is permeated by urban development or solitary buildings and when land uptake per inhabitant or job is high" (Jaeger and Schwick, 2014, p. 295). This implies that as the amount of built-up area and its dispersion and land uptake per inhabitant (or job) increase, the level of urban sprawl increases as well (Jaeger and Schwick, 2014).

Behnisch et al. (2022b) demonstrated that urban sprawl on the planet almost doubled between 1990 and 2014. A continuation of this type of urban expansion would have numerous additional negative impacts on climate, biodiversity, agricultural soils, and people's lives. This would result in an increase in greenhouse gas emissions, destruction of wildlife habitats, and a reduction of essential ecosystem services, among other effects (Behnisch et al., 2022b). Recent research on the impacts of urban sprawl on environmental sustainability in cities has primarily concentrated on its effects on transportation and energy efficiency. For instance, in Germany, buildings contribute to as much as 30% of the country's greenhouse gas emissions, encompassing both direct and indirect emissions (BMUB, 2016). Therefore, it is crucial to establish specific sustainability criteria, such as urban form and density and biodiversity.

Methods to measure urban sprawl quantitatively have been limited so far, and the suitability of some widely used methods such as entropy is questionable (Nazarnia et al., 2019). The main method used for this study is the Weighted Urban Proliferation (*WUP*) which defines sprawl in numeric values. The *WUP* value combines the three essential components of urban sprawl: (1) the proportion of the built-up area in a reporting unit (in %), (2) the degree of scattering of built-up areas (dispersion), and (3) the land-uptake per person (Schwick et al., 2012; Jaeger and Schwick, 2014).

By utilizing the *WUP* method, different planning scenarios for built-up areas can be analyzed in terms of their environmental sustainability and with respect to their impacts on sprawl

(Hennig et al., 2015). The use of scenarios in land-use planning for representing potential future trajectories has been discussed in the planning literature for decades. Scenarios depict land-use patterns that would be the expected or potential results of planning policies and regulations at a specific time (Xiang and Clarke, 2003). In this study, five reference scenarios is used, almost all of them are similar to the scenarios that have been used by Schwick et al. (2018). These scenarios demonstrate various possible development paths by changing a variable in each while keeping the rest constant for the target year, which is 2050. Details on each scenario are explained in sections 3-4, 4-3, and 4-4.

Urban growth management includes an integrated set of policies for keeping or achieving the desired land uses in cities (Ewing et al., 2022). Researchers have proposed a variety of urban growth management strategies for controlling urban sprawl (Hersperger et al. 2020). For instance, Pourtaherian and Jaeger (2022) studied the effectiveness of greenbelts at mitigating urban sprawl. One way to help curb urban sprawl is to establish suitable reference values. These values (e.g., target) are used to assess whether the occurring developments are sustainable or not. Addressing qualitative targets may seem more approachable than quantitative ones as they are the results of planning goals, with no exact amounts or numbers specified, whereas setting quantitative targets usually faces some difficulties. One reason is the limitation of available data and theory, and another is little political support as flexibility of planning strategies is preferred, and qualitative targets are better for this use (Knoepfel et al., 2011). However, it is more difficult to assess if the qualitative targets have been achieved. Quantitative values allow a better, clearer, and more straightforward understanding of the problem, and they provide concrete evidence of the extent of urban growth. The use of quantitative values allows easier and more detailed comparisons over time (Jaeger and Schwick, 2014). Targets and limits have already been established for several other environmental topics, such as soil pollution, noise pollution, and air pollution. However, according to our review of the literature, there is a significant gap in terms of reference values (targets and limits) for urban areas.

Urban sprawl can be quantified and assessed at multiple spatial scales. For example, Hennig et al. (2015) studied urban sprawl in Europe at 3 different scales, country-wide (NUTS-0, NUTS: Nomenclature of Territorial Units of Statistics), NUTS-2 (used for regional policies), and a 1-km^2 grid (used for Land and Ecosystem Accounting). The case study in this thesis includes

Germany's planning regions and federal states. Federal states are examined alongside planning regions, as they are widely recognized administrative spatial units.

According to the United Nations (2019), Europe stands out as one of the most heavily urbanized regions globally, as demonstrated by the fact that 74 percent of its population resided in urban areas in 2018. The German Advisory Council on the Environment has recently recognized the significant problem of high land take as an ongoing environmental concern. From 1990 to 2014, there was an average annual increase of 1.45% in urban sprawl across Germany (Behnisch et al. 2022a). Therefore, studying current trends and future scenarios of urban sprawl in Germany is important. Germany has 16 federal states and 111 planning regions which will be used as reporting units of this research. The use of 111 planning regions is beneficial as they correspond to the spatial allocation of control instruments for settlements and land development.

Based on the increase of urban sprawl in the last 30 years and on five different potential future scenarios of urban sprawl in Germany, my thesis will determine targets and limits to urban sprawl using the Weighted Urban Proliferation (*WUP*) method. The objective of this research is to propose suitable reference values for urban sprawl (targets, limits, and warnings) that could serve as guidance for a trend reversal toward sustainability. These values will be based on an assessment of several potential future scenarios of urban development in terms of their sustainability. This project will help addressing the growing challenge of urban sprawl more effectively in planning and policy in the future. According to this objective, my research addresses four main questions:

1- What are the current trends in urban sprawl in the various reporting units in Germany?

2- What future urban development scenarios in the reporting units (planning regions and federal states of Germany) can be considered more sustainable?

3- What levels of urban sprawl would these more or less sustainable scenarios correspond to in the various reporting units by the year 2050?

4- What would be the corresponding targets and limits to urban sprawl for the various reporting units by the year 2050?

This thesis begins with an overview of relevant literature related to urban sprawl, including its definition, historical context, causes, consequences, and commonly used measurement methods, along with related themes such as the sustainability paradigm. Section 3 outlines the main methodology used to assess urban sprawl, including future scenario development, target and limit setting, data sources, and reporting units. Section 4 presents the results, which are then examined in greater depth in the discussion (Section 5). The thesis concludes with a final summary and reflection in the conclusion section.

2- Literature Review

2-1- Literature Map

Reviewing the literature is a crucial component of thesis writing. In this section, a literature map provides an overview of the topics covered and highlight some of the primary sources used in its construction (Fig. 1).

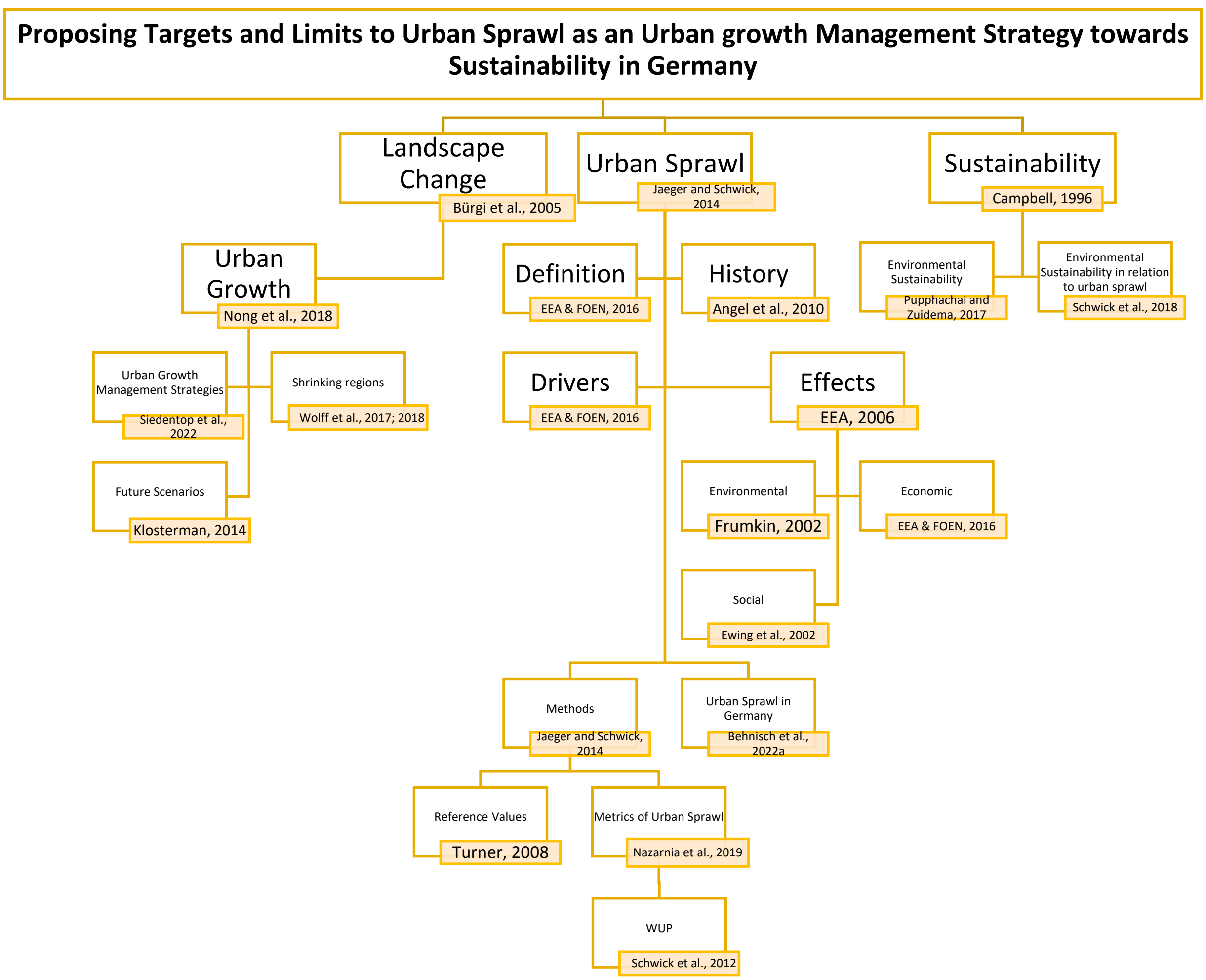

Figure 1 - Literature map

2-2- Landscape Change

The landscape is the primary sphere in which the combined impacts of societies on their environments can be seen. Landscapes naturally change since both societies and nature are dynamic (Bürgi et al., 2005). The definition of land take is "the conversion of natural or semi-natural land to urban or other artificial lands" (European Environment Agency, 2019). The world's population growth has caused many natural landscapes to be converted to urban land use, changing how people interact with the environment on a global scale (Rogan and Chen, 2004).

Human actions, such as the use of land for food production or settlements, are to blame for the majority of landscape changes in the present and recent past (Turner et al., 1995). For instance, in terms of urbanization, a significant portion of agricultural lands and forests has been converted into urban areas. Additionally, mining and oil extraction have occurred globally to meet human energy demands, directly impacting land use and land cover (Basommi et al., 2016).

Landscape change is the outcome of various interacting factors, including political, economic, cultural, technological, and environmental driving forces, and the respective actors. Urban land change extends beyond the city center and encompasses various rural areas connected to the city, with significant effects on rural regions, making it a subject that should receive greater focus within land-change research (Bürgi et al., 2005; Brenner and Schmid, 2015; Hersperger et al., 2018).

2-3- Different Forms of Urban Growth

As cities continue to grow quickly, it is crucial to find a more sustainable way to develop them to reduce the negative effects of urbanization on the natural environment (Soga et al., 2014). Three types of urban growth can be distinguished (Fig. 2): (a) infilling growth, which fills in existing open spaces within an urbanized area and increases the built-up area's contiguousness; (b) edge expansion, which describes non-infill development that crosses the current boundaries of an urban area and extends outward from existing development; and (c) unconnected ("spontaneous" according to Nong et al.) growth, which occurs outside of the pre-growth patch, forming a new small urban core but has the greatest impact on the fragmentation of open lands (Nong et al., 2018).

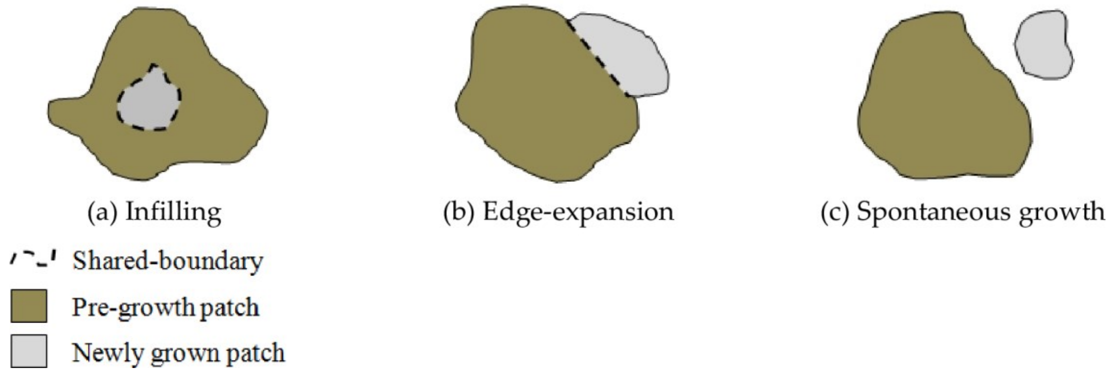

Figure 2 - Three urban growth types (source: Nong et al., 2018).

In the field of urban planning, various principles and objectives such as "compactness", "sustainable development", and "polycentricity" are employed to support the management of urban growth (Fertner et al. 2016). The specific choice of these principles for application depends on factors such as the socio-economic context, cultural values, historical background, planning system, governance structures, and institutional arrangements of the region under consideration (Fertner et al. 2016; OECD 2018).

2-3-1- Urban Growth Management Strategies

Urban growth management includes an integrated set of policies for keeping or achieving the desired land uses in cities (Siedentop et al., 2022). Researchers have proposed a variety of urban growth management strategies for controlling urban sprawl (Hersperger et al., 2020; Ewing et al., 2022). In the following paragraph, a couple of proposed policies from the literature are presented:

1- Sustainable development: The goal of sustainable development as a growth management strategy is to restrict growth to the extent that public facilities and services are in place to handle this increase (Burchell et al., 1998), which was largely inspired by the 1992 World Congress on Sustainable Development held in Rio de Janeiro.

2- Pourtaherian and Jaeger (2022) studied the effectiveness of greenbelts at mitigating urban sprawl. Their results show that greenbelts have generally proven successful in reducing urban sprawl and, in many cases, preventing it. Furthermore, some studies in Germany indicate that about 60% of Germany's planning regions have incorporated greenbelts into their development strategies, often in conjunction with other policies for managing urban growth (Domhardt et al., 2006; Finke et al., 1993).

3- A policy known as “smart growth” encourages development that is compact, transit-oriented, and walkable. It seeks to promote urban growth in a more sustainable way while minimizing sprawl (Ewing & Hamidi, 2014; Hamidi & Ewing, 2014).

4- Zoning laws are a collection of rules that control how land is used in a certain location. Zoning can assist the protection of open spaces and natural resources while also regulating the size, density, and use of new areas under construction (Parker & Thurman, 2013).

The picture below indicates the evolution of some major urban growth management strategies applied over time in different regions (Fig. 3).

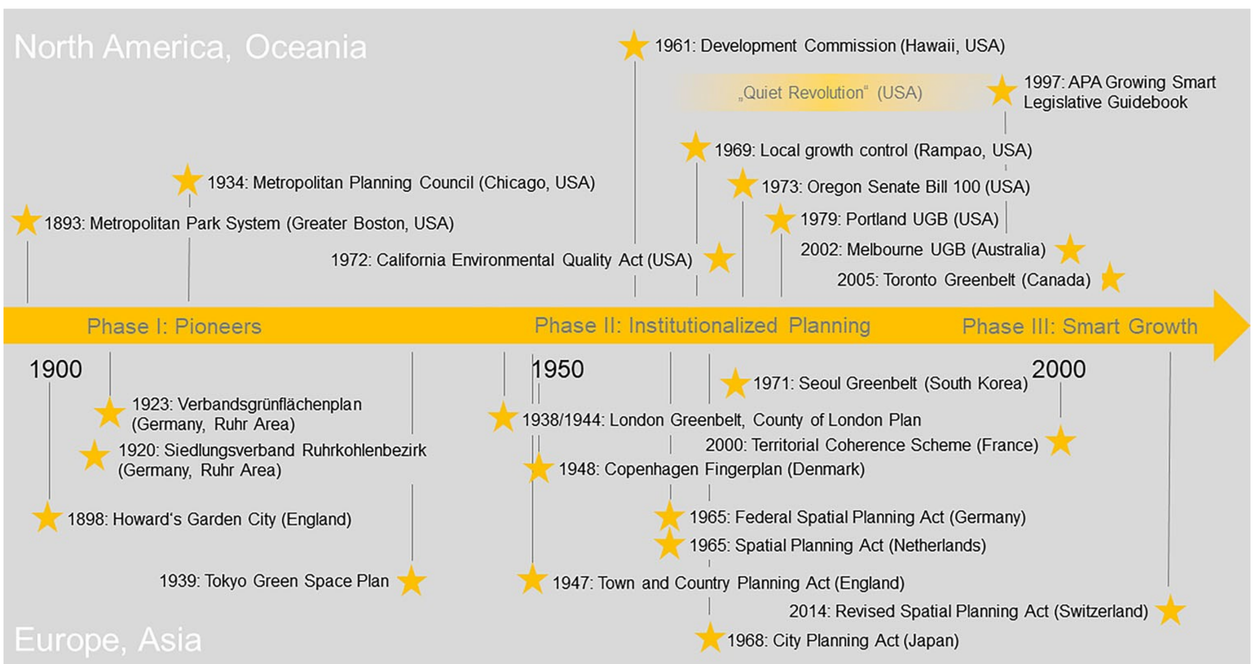

Figure 3- Evolution of urban growth management strategies (source: Siedentop et al., 2022).

2-3-2- Shrinking Regions

Urban shrinkage is broadly defined as a condition in which territories experience population decline due to demographic or economic factors, and may or may not undergo physical spatial contraction (Sousa, 2010; Reis, Silva, & Pinho, 2015). At its center, shrinkage reflects long-term population loss, a trend observed across both Europe and the United States (Wolff & Wiechmann, 2018; Hartt, 2019). While most academic research has focused on demographic and socioeconomic aspects, spatial patterns of shrinkage have received less attention (Wolff et al., 2018).

In the United States, the second half of the 20th century was marked by widespread urban decline, marked notably by population loss in city cores due to rapid suburbanization. This shift was strongly supported by federal policies, particularly highway expansion, contributing to the deterioration of inner-city neighborhoods and widespread spatial fragmentation (Beauregard, 2009; Herrmann et al., 2020). Similar trends have emerged in European cities, driven by ageing populations and internal migration from less developed to more competitive regions. A key turning point in the European context was the East German housing market crisis of the early 1990s, which brought renewed attention to the dynamics of urban shrinkage (Wolff & Wiechmann, 2017).

In Germany, the term *schrumpfende Städte* (shrinking cities) was introduced by Häußermann and Siebel (1988) to describe population and economic decline caused by deindustrialization. First observed in West Germany during the 1980s, the phenomenon became more pronounced in East Germany after reunification in 1989. There, a combination of deindustrialization, suburbanization, and demographic decline produced a distinctive form of shrinkage (Oswalt, 2006). Eastern Germany now has one of the lowest industrial employment levels in Europe and unemployment rates that are twice as high as in the west Germany (Prigge, 2006; Martinez-Fernandez et al., 2012; Pallagst, Fleschurz, & Said, 2017).

A particularly paradoxical outcome of urban shrinkage is its coexistence with urban sprawl, resulting in urban forms where fewer people and activities are spread across increasingly expansive areas (Couch et al., 2005; Siedentop & Fina, 2008). These "shrinkage-sprawl" patterns resemble classic urban sprawl observed in growing cities—characterized by fragmented, low-density development—but are typically accompanied by higher vacancy rates, land abandonment, and inner-city deterioration in shrinking regions (Reis et al., 2015). In this way, urban sprawl can sometimes contribute to or accelerate the process of urban shrinkage.

Historically, urban planning in both the U.S. and Europe has operated under a "growth paradigm," assuming that growth is both natural and desirable (Bontje, 2004; Hollander et al., 2009; Rink & Kabisch, 2009; Sousa, 2010; Wiechmann & Pallagst, 2012). Only in recent years has this mindset begun to shift. As urban shrinkage becomes a more frequent reality, planning scholars and practitioners have started to challenge traditional growth-centered approaches. Across perspectives—from socially just smart decline to more radical calls for degrowth—many now argue that shrinking cities should embrace their reduced scale rather than pursue growth uncritically (Hollander et al., 2009; Fernandez & Hartt, 2021).

2-4- Future Scenarios

"Scenarios are sets of narratives about the future; they have been employed by decision makers in the business community and elsewhere for several decades as an alternative to predictions, forecasts, and other single-future strategic planning processes" (Bennet et al., 2016: 445). Scenarios assist in building common understandings of potential developments, choices, and actions. They are not forecasts, predictions, or personal preferences. Instead, they are cohesive and credible stories that depict diverse paths leading to different possible futures (Davis, 2002). They are "plausible" and "alternative" views of the futures that arise from a particular set of assumptions and relationships (Lumeng & Jianguo, 2022).

Scenario planning, although not a new concept in urban planning, has gained popularity, especially with the support of computer tools that facilitate spatial data visualization and interactive analysis (Klosterman, 2013). In the public sector, a diverse group collaborates to develop various scenarios challenging assumptions about the future. Successful scenario planning enables community members to learn, identify control factors, acknowledge limitations, and assess the implications of present choices (Klosterman, 2013).

2-5- Urban Sprawl

Urban sprawl refers to dispersed and low-density growth which has numerous negative environmental, social, and economic impacts. Therefore, it is unsustainable (EEA and FOEN, 2016). Despite significant attempts to curb urban sprawl, it has become more common in many cities around the world (Bruegmann, 2008b). The upcoming paragraphs discuss various aspects of urban sprawl, including its origins, definition, driving factors, and consequences.

2-5-1- History of Urban Sprawl

Numerous fields, each with their own perspective on the topic, have examined urban sprawl, including landscape ecology, transport planning, geography, and urban economics (Arribas-Bel et al., 2011). Earle Draper of the Tennessee Valley Authority used the word "sprawl" for the first time in 1937 while speaking at a national gathering of planners. Sprawl was described as an unaesthetic and uneconomic style of residence (Wassmer, 2002). However, urban sprawl can be traced further back in history.

If we consider sprawl as the expansion of people into less densely populated areas without over-arching planning or regulation, then sprawl is as old as cities (Bruegmann, 2008a). In fact, according to Bruegmann (2008b), the history of urban sprawl predates the advent of cars. Throughout history, whenever families could afford it, they often sought to leave the city for suburban or countryside retreats, a practice already evident in ancient Rome when those owning private transportation (such as horses and carriages) could enjoy coastal or hillside getaways. In the modern era, before the widespread use of cars, a form of sprawl existed in London where affluent individuals from central city areas sought to escape the spread of disease and improve sanitation by relocating to more distant suburbs or countryside retreats (Bruegmann, 2008b).

Amid the era of rapid urbanization and the emergence of industrial cities, which began in the late seventeenth century and extended into the early decades of the twentieth century, numerous cities experienced significant expansion beyond manageable walking distances. Furthermore, during the initial stages of industrialization, central population densities in some cities increased, often quite rapidly, as a substantial influx of individuals moved from rural regions or immigrated from overseas. As observed by Clark, a pioneer in the study of urban population density (Angel et al., 2010): “The advent of the nineteenth century industrial city compelled people to live at far greater densities than had ever been known before, with consequent effects upon their health and well-being” (Clark, 1951, p. 492). As a result of dense, polluted cities, in the nineteenth century, in Western nations, a concern for the quality and beauty of the environment, particularly in towns and cities, arose. Urban land use and architecture planning and design significantly improved, and open green areas, tree planting, parks, and public gardens received significant attention (Haber, 2007).

With the introduction of automobiles, which allowed people to go farther from the city center, cities started to expand beyond their historical bounds in the early 20th century (Galster et al., 2001). With the building of new highways and the advent of suburbanization in the post-World War II era, the trends towards urban decentralization and low-density development accelerated (Jackson, 1987). Large amounts of agricultural and natural land have been converted to urban usage as a result of this process, with severe environmental, social, and economic repercussions (Pickett et al., 2004).

2-5-2- Definition of Urban Sprawl

Defining urban sprawl in a clear way is sophisticated. This may be the result of a number of factors, such as various interpretations based on the authors' research areas and academic specialties (Bhatta et al., 2010), or conflation with other terms with a similar meaning, such as suburbanization (Franz et al., 2006). Accordingly, a variety of definitions of urban sprawl have been proposed in the past decades until recent years (Tab. 1). A helpful definition suggests that "urban sprawl is a phenomenon that can be visually perceived in the landscape. A landscape suffers from urban sprawl if it is permeated by urban development or solitary buildings and when land uptake per inhabitant or job is high" (Jaeger and Schwick, 2014, p. 295; Jaeger et al., 2010a). According to this definition urban sprawl has three dimensions: 1) the amount of built-up area, 2) the dispersion of built-up area, and 3) land uptake per person or job (Fig. 4).

Table 1 - Examples of definitions of urban sprawl from the literature

Author, Year	Definition
The Sierra Club (1999, p. 1)	“low-density development beyond the edge of service and employment, which separates where people live from where they shop, work, recreate and educate-thus requiring cars to move between zones”.
EEA (2006, p. 6)	“The physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas”.

Jaeger and Schwick (2014, p. 295-296)	"Urban sprawl is a phenomenon that can be visually perceived in the landscape. A landscape suffers from urban sprawl if it is permeated by urban development or solitary buildings and when land uptake per inhabitant or job is high. the more area built over in a given landscape (amount of built-up area) and the more dispersed this builtup area in the landscape (spatial configuration), and the higher the uptake of built-up area per inhabitants or job (lower utilization intensity in the built-up area), the higher the degree of urban sprawl".
OECD (2018, p. 29)	"An urban development pattern characterized by low population density that can be manifested in multiple ways. That is, an urban area may be sprawled because the population density is, on average, low. Furthermore, urban areas characterized by high average density can be considered sprawled if density varies widely across their footprint, leaving a substantial portion of urban land exposed to very low-density levels. Urban sprawl can also be manifested in development that is discontinuous, strongly scattered and decentralized."

All the definitions included in Tab. 1 share the same characteristic of "low density" and a "dispersed" kind of development.

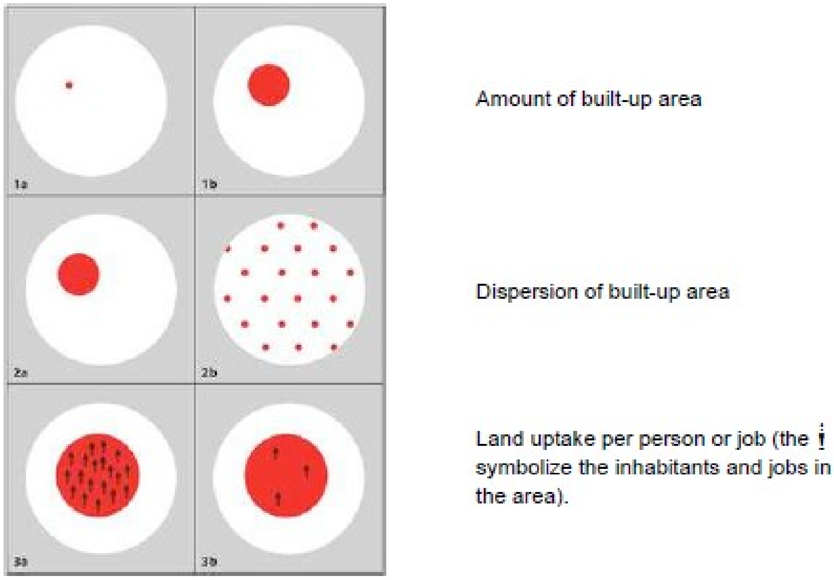

Figure 4 - The three dimensions of urban sprawl according to the definition by Jaeger and Schwick, (2014)

2-5-3- Drivers of Urban Sprawl

According to the literature, drivers of urban sprawl are divided into the following categories: demographic (such as migration and attraction toward urban life), socio-economic (such as a preference for living in single-family houses, living in low-density areas, and owning personal automobiles), political (such as governmental policies on taxes), technological (such as transportation means and road infrastructure), and geophysical (location and land suitability for expanding the built-up areas) (Bart, 2010; EEA & FOEN, 2016).

According to Angel et al. (2010), urban sprawl occurs when cities spread out over large areas due to a growing urban population and an increase in land uptake per person. Moreover, according to Marshall (2001) and Torres et al. (2016), urban sprawl and transportation have a major connection that makes it difficult to determine to what degree each one causes the other. The expansion of highways and the advancement of telecommunication are major contributors to urban sprawl.

2-5-4- Effects of Urban Sprawl

Similar to many other phenomena, urban sprawl has both negative and positive impacts. Urban sprawl has some positive effects, such as meeting people's desire for affordable detached houses with yards and increased privacy (Bhatta, 2010). It can also help reduce problems like lack of garden areas for leisure, increased noise, and higher stress levels that might occur if people were restricted to living in crowded city areas (Berry, 2007). However, the negative impacts are more numerous. Many of the environmental, economic, and social challenges that cities face can be traced back to particular aspects of urban development patterns. Using the same classification (environmental, economic, and social), the subsequent paragraphs provide examples of each.

2-5-4-1- Environmental Impacts

Energy inefficiency is one of the main results of sprawl. Higher commuting durations result in higher greenhouse gas emissions, leading to increased air pollution and contributing to climate change. Other environmental impacts include higher habitat fragmentation, ecosystem disruption, and declining wildlife populations (Newman & Kenworthy, 1988; Bhatta, 2010). Energy inefficiency can also stem from the type of housing. A study conducted in 17 regions of Spain analyzed the impact of urban sprawl on power consumption through quantile regression. The findings offer evidence of lower energy efficiency of single-family homes in dispersed urban areas (Navamuel et al., 2018).

Another major impact of urban sprawl is its linkage with climate change. When a city moves into the path of higher dispersion, it also moves into the path of higher private car use. The intense use of cars as the primary mode of urban transportation by an overly high percentage of the world's urban population is one of the key contributors to global warming (Bart, 2010). According to a study done in the USA, the number of high-heat events in sprawling cities doubled annually during the summer when compared to more compact cities. The data analysis from the same study also indicated that, between 1992 and 2001, The rate of deforestation in the most sprawling areas was more than twice that in the most compact cities (Stone et al., 2010).

The amount and quality of water supply may be in danger due to sprawl. As forest cover is destroyed and impermeable surfaces are developed across broad regions, rainfall is less effectively absorbed and returned to subterranean aquifers. Instead, a greater amount of stormwater is carried downstream into streams and rivers. According to one study, runoff accounts for around only 4% of rainfall on undeveloped grassland compared to 15% in suburban areas (Frumkin, 2002). As urban areas expand, they often cover land that used to be forests or farmland. This means that instead of being absorbed into the ground, rainwater is unable to penetrate the concrete and asphalt surfaces that now cover the land. This leads to a decrease in the amount of water that is absorbed into groundwater aquifers. Additionally, the loss of soil permeability and increased pollution from runoff from parking lots and roads are negative consequences of urban sprawl (Frumkin, 2002; EEA, 2006).

2-5-4-2- Economic Impacts

Urban sprawl is frequently seen as beneficial economically. However, many expenses are left out of such estimates of the economic benefits of sprawl. The expenses related to the environmental, social, and health implications of sprawl are typically not considered when estimating the economic net benefits of sprawl. For example, increases in expenditure for infrastructure building and maintenance are largely covered by taxes paid from the public but are not considered in the estimates (EEA & FOEN, 2016). Moreover, suburbanization, illustrated by the growth of shopping malls on city outskirts, often leads to the decline of city centers and small businesses. Despite initiate expectations, these malls can bring economic challenges, leading to issues like central decay and increased costs for cities (Evers, 2004).

2-5-4-3- Social Impacts

The most frequently stated social effects of urban sprawl in the literature include the lack of social connection, the lack of variety in the physical forms of sprawled areas, and restricted access to amenities, services, and jobs. These impacts are especially noticeable among children, the elderly, and marginalized populations (Ewing et al., 2002; EEA & FOEN, 2016).

Sprawl is a type of urban growth that can limit the access of underprivileged part of the population to economic opportunities. Poverty is concentrated in the areas that are left behind when businesses, decent schools, and other resources depart from the center of cities (Jargowsky, 1997). Some argue that the problem with sprawl is not with people who have relocated to the suburbs, but with people who have been left behind (Glaeser & Kahn, 2004). An abandoned underclass of society whose incomes cannot support a lifestyle centered on one or several cars has been developed in some cities such as Los Angeles in California as a result of the migration of jobs and residents from inner cities (Glaeser & Kahn, 2004).

Some research about the relationships between social capital and the built environment has shown that individuals who reside in neighborhoods that have mixed-use developments and are pedestrian-friendly tend to have higher levels of social capital compared to those living in suburbs that are car-oriented (Leyden, 2003).

2-5-5- Urban Sprawl in Germany

Europe ranks among the most urbanized regions globally, with 74 percent of its population residing in cities (UN, 2019). A research by Hennig et al. (2015) revealed that an extensive part of Europe is affected by urban sprawl. As reported by the German Federal Office for Building and Regional Planning, German cities are surrounded by suburbanized regions (Strubelt, 2001). In 1996, 11.8 % of Germany's land was dedicated to settlements and transportation infrastructure. By 2004, this figure had already increased to 12.8 %, which amounted to 4.5 million hectares (Statistisches Bundesamt Deutschland, 2005). Although there are regions, such as East Germany, where the human population is not increasing, the expansion of built-up area has persisted in most of these regions, even in cases of declining population (Haase et al., 2013). In general, between 1990 and 2014, Germany experienced an average annual increase in urban sprawl of 1.45% (Behnisch et al., 2022a).

In 2002, the German federal government introduced its initial sustainability strategy named 'Perspectives for Germany' (Federal Statistical Office of Germany, 2021). One of its main goals was to reduce daily land consumption to less than 30 hectares by 2020. However, between 2018 and 2021, 55 hectares of land were newly dedicated to settlements and transportation infrastructure per day on average in Germany (Fig. 5). According to the sustainability strategy's objectives, the revised aim now is to limit daily land consumption to less than 30 hectares per day by 2030 (Germany’s Integrated Environmental Programme 2030, 2016; Federal Statistical Office of Germany, 2021). Additionally, in 2007, the National Strategy on Biological Diversity set the goal of developing a suitable urban sprawl indicator "by the end of 2008" but this has still not been implemented as of now (BMU, 2007).

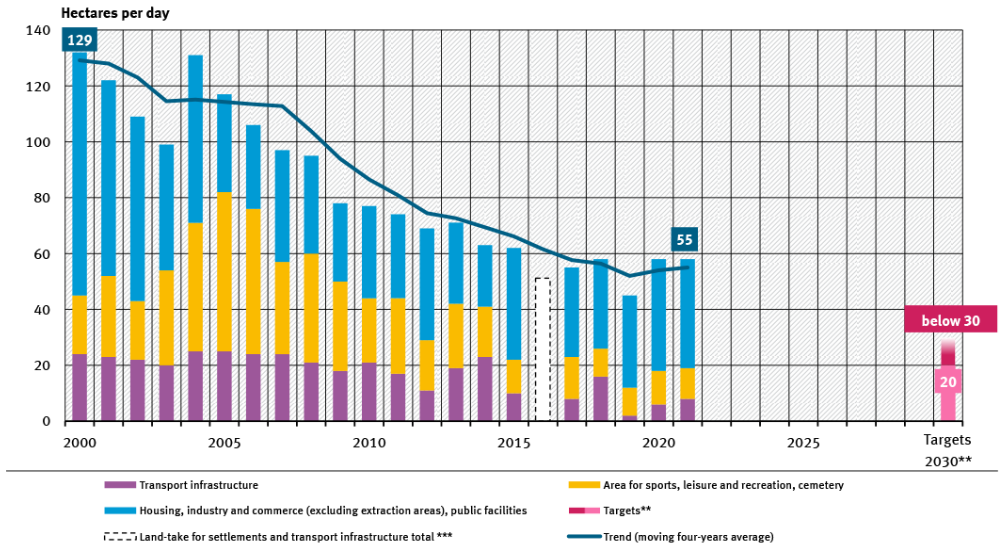

Figure 5 - Land-take for settlements and transport infrastructure in Germany between 2000 and 2021 and the revised target for 2030 (source: Federal Statistical Office of Germany, 2021)

2-6- Methods for the measurement of urban sprawl

2-6-1- Metrics of urban sprawl

Various statistical and spatial metrics, such as population density, accessibility, and aesthetic measures, can be utilized to measure the level of urban sprawl. For example, Galster et al. (2001) developed a measure of urban sprawl that incorporates eight conceptual dimensions of land use patterns, including density, continuity, and proximity. Similarly, Ewing et al. (2002) used a principal component analysis to summarize 22 related variables into four conceptual dimensions of urban sprawl, including residential density and accessibility of the street network. Frenkel and Ashkenazi (2008) evaluated urban sprawl in Israeli cities by considering the dimensions of density, scatteredness, and mixture of land uses. Wissen et al. (2011) used Urban Dispersion, Total Sprawl, Urban Permeation, and Sprawl Per Capita as their metrics for measuring and predicting sprawl in Switzerland.

The use of Shannon’s entropy for assessing urban sprawl is perhaps the most widely used technique, but according to Bhatta et al. (2010) it is “not free from all nuisances”. Therefore, the authors emphasize the need for the development of more reliable measurement techniques for urban sprawl. Also, entropy is significantly influenced by the selection of zones within a landscape (Bhatta et al., 2010; Nazarnia et al., 2019). Jaeger and Schwick (2014) utilized the Weighted Urban

Proliferation (WUP) method in their article “Improving the measurement of urban sprawl” which is based on urban permeation, dispersion, and utilization density. Clearly, over time and according to different definitions of sprawl, scientists have used different measures for urban sprawl.

2-6-2- Weighted Urban Proliferation (WUP)

Schwick et al. (2012) proposed the Weighted Urban Proliferation (WUP) method, which is derived from the method developed by Jaeger et al. (2010b) as a measure for investigating and evaluating urban sprawl. This method includes three components:

1- Percentage of built-up areas (PBA): This component calculates the percentage of a region's land area that is occupied by built-up areas like buildings, roads within towns and cities, parking lots, and other infrastructure. A higher PBA denotes greater urban sprawl.
2- Dispersion of the built-up areas (*DIS*): This component calculates the level of scatteredness of the built-up area throughout the landscape. More dispersed urban growth is indicated by a higher *DIS*.
3- Land uptake per person (LUP): This component describes the use of built-up area by people (inhabitants or jobs) working or living in that area.

WUP is calculated with the following formula:

$$WUP = (PBA \times DIS) \times w_1(DIS) \times w_2(LUP) \, ,$$

$w_1(DIS)$ and $w_2(LUP)$ are weighting functions for dispersion and land uptake per person, respectively. WUP is expressed in urban permeation units per m^2 of land (UPU/m^2).

2-6-3- Reference Values

One of the main sources about the limitations to growth on the planet is a book called "The Limits to Growth," published in 1972. It presented the findings of a study by Meadows et al. about the growth of the human population and their resource use. The study used a computer model called World3, which allowed the researchers to analyze the interactions of five subsystems of the global economic system, including population, food production, industrial production, pollution, and consumption of non-renewable natural resources. If the identified trends of the 1960s in the five mentioned subsystems continue, the planet's limits will likely be reached in the 21 century between 2024 and 2030, leading to an uncontrollable decline in both population and industrial production (Nebel et al., 2023). However, it was possible to change these trends and establish a sustainable state of ecological and economic stability, ensuring everyone's basic needs are met and equal opportunities for individual well-being. The sooner people worldwide choose this path, the better the chances of success and avoidance of a collapse (Meadows et al., 1972, Turner, 2008). This study highlights the need for systems thinking[1] in decision-making related to sustainability.

One approach toward curbing urban sprawl is to establish suitable reference values. These values (e.g., targets) would then be used to assess whether the occurring developments are desirable or not. Addressing qualitative targets may seem more approachable than quantitative ones as they are the results of planning goals, with no exact amounts or numbers attached, whereas setting quantitative targets usually faces some difficulties. One reason is the limitations of available data and theory, and the other reason is the little political support as flexibility of planning strategies often is preferred, and qualitative targets are better for this use (Knoepfel et al., 2011). However, it is much more difficult to assess to what extent the qualitative targets have been achieved. Quantitative values allow a better, clearer, and more straightforward understanding of the problem, and they provide concrete evidence of urban growth. The use of quantitative values allows easier and more detailed comparisons over time and between different locations (Jaeger and Schwick, 2014).

Such targets and limits have been established for several other environmental topics, such as soil pollution, noise pollution, and air pollution. For instance, the United Nations' Sustainable Development Goals (SDGs) address objectives to reduce human exposure to air pollutants and lower the associated health threat from both household and ambient sources.

According to the World Health Organization (WHO), the establishment of such reference values is guided by multiple criteria. Initially, toxicological and epidemiological studies are used to identify what dose of pollutants will pose health risks—such as increased rates of asthma or mortality at certain NO_2 levels. These scientific findings are then followed by an assessment of technical and practical feasibility, evaluating whether the proposed thresholds can be effectively measured, monitored, and applied using available technologies and if it could be a realistic policy.

While WHO provides health-based guideline values, it is ultimately up to national authorities to translate these into enforceable standards. For example, in collaboration with WHO,

[1] Systems thinking is an approach to understanding the complexity of the world by viewing it in terms of wholes and relationships, rather than breaking it down into isolated parts and studying them in isolation

the Swiss Tropical and Public Health Institute (Swiss TPH) compiled global data on ambient air quality standards across UN Member States for pollutants such as $PM_{2.5}$, PM_{10}, NO_2, and SO_2. (Kutlar Joss et al., 2017; WHO, 2021). The adoption of such limits depends not only on scientific evidence but also on national regulatory frameworks. According to my review of the literature, there is a large gap in terms of reference values for urban sprawl.

2-7- Sustainability and Sustainable Development

The concept of sustainability has been frequently debated, and there is a range of diverse research available on this topic. Sustainable development does not offer a precise definition but rather provides a general framework for shaping urban policies (Pupphachai and Zuidema, 2017). This situation has led to the creation of the Sustainable Development Goals (SDGs), which include 17 main goals and 169 connected targets set by the United Nations in 2015, based on each country's specific priorities (UN, 2015).

In the 1960s and 1970s, growing awareness of environmental pollution sparked discussions about sustainability and sustainable development. The concept of sustainable development began to gather momentum in the 1980s, connecting the protection of the environment with meeting human needs (IUCN, 1980). The Brundtland Report (WCED, 1987) defined sustainable development as satisfying present needs without compromising the ability of future generations to meet their own needs. This definition allows for flexible interpretations (Prugh and Assadourian, 2003).

The continuous expansion of urban areas leads to a cumulative transformation of the environment that will be inherited by future generations, posing potential threats to the future. Hence, the present generation holds the responsibility of preserving resources that are shared across generations. Urban sprawl, resulting from numerous individual actions that accumulate and have long-term effects, raises concerns of intergenerational justice. In order to address intergenerational environmental justice, a fair distribution of resources among generations is essential (Habib 2013, Fritsch 2018). Therefore, a shift towards a turn-sharing approach to sustainability is advocated, encouraging each generation to perceive itself as a collective entity with a collective responsibility during their respective time of presence on the planet (Fritsch, 2018).

Sustainable development encompasses the integration and understanding of complex interconnections among the environment, economy, and society (Giovannoni & Fabietti, 2013). In order to be economically sustainable, an economic system must be able to produce goods and services continuously, and avoid excessive debt and imbalance among sectors. An environmentally sustainable system must maintain a stable resource base, avoid excessive use of renewable and non-renewable resources, and ensure biodiversity conservation, atmospheric stability, and many other ecosystem functions. A socially sustainable system should be fair in the distribution of public goods and provide social services such as health care and education, gender equality, and political accountability and participation (Harris, 2003).

In practice, planners often face constraints that limit their ability to achieve a balance between the three goals of sustainability. The existing sustainability concept faces critiques of vague idealism (Campbell, 1996). According to Campbell (1996) advocates of sustainable development often idealize pre-industrial, indigenous, sustainable cultures, offering inspiring yet limited applicability to contemporary challenges. Therefore, focusing on one aspect of sustainability and analyzing the relation between that specific aspect and urban sprawl seems more achievable in the context of a MSc thesis.

2-7-1- Environmental Sustainability

While the multidimensionality of sustainability has been discussed extensively, it has often been categorized primarily in terms of environmental concerns in the past three decades (Drexhage & Murphy, 2010). The term "sustainability" gained popularity in the 1970s, primarily in relation to environmental issues. It was initially referred to as an "environmentally responsible development" by scientists at the World Bank (World Bank, 1992), and later as "environmentally sustainable development" (Serageldin & Streeter, 1993). Finally, the current concept of environmental sustainability was developed. According to Goodland, environmental sustainability “seeks to improve human welfare by protecting the sources of raw materials used for human needs and ensuring that the sinks for human wastes are not exceeded, in order to prevent harm to humans” (Goodland, 1995, p. 3). Christensen (1989) characterizes environmentally sustainable development as a development pattern that upholds the presence of an adequate amount of natural systems (ecosystems) as the foundation of human welfare.

Global data indicate a clear decline in environmental sustainability, highlighting a worsening situation worldwide often referred to as the “Great Acceleration” in the Anthropocene (Steffen et al, 2015). In fact, it is accurate to state that the world is currently experiencing an environmental and a climate emergency. Urgent action is necessary to effectively address this issue by implementing evidence-based solutions and achieving set targets at both micro and macro scales (Arora and Mishra, 2019).

In 2015, a global commitment was made through the United Nations Headquarters in New York with the establishment of the "2030 Agenda," including 17 Sustainable Development Goals with specific targets and indicators. Table 2 shows some of the targets and goals of the United Nations Sustainability agenda related to environmental sustainable development and their possible relation to urban sprawl which shows the importance of this topic.

Table 2 - UN sustainable development goals and their relation to urban sprawl (source: United Nations, 2018)

Goal	Target	Relation to urban sprawl
SDG 15: Life on Land	Taking urgent action to decrease the degradation of natural habitats and biodiversity	direct
SDG 13: Climate Action	Integrate climate change measures into national policies, strategies and planning	indirect
SDG 11: Sustainable Cities and Communities	Reduce the adverse per capita environmental impact of cities, such as paying special attention to air quality	direct
SDG 6: Clean Water and Sanitation	Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	Indirect
SDG 3: Good Health and Well-being	Reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution	indirect

2-7-2- Environmental Sustainability in Relation to Urban Sprawl

Urban sprawl is closely linked to several dimensions of environmental sustainability. To explore this relationship, various criteria and indicators have been identified and studied. Examining these criteria highlights the importance of mitigating urban sprawl to achieve greater environmental sustainability. Two main criteria stand out in relation to urban sprawl (Fig. 6).

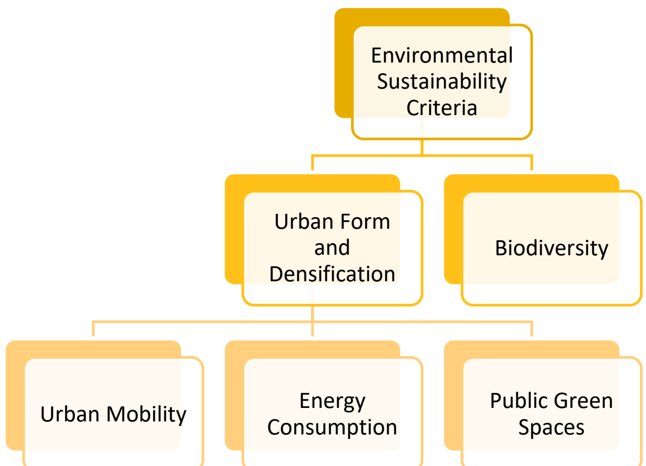

Figure 6 - Environmental Sustainability Criteria Related to Urban Sprawl

Urban form and Densification: The literature about the impact of urban sprawl on the environmental sustainability of urban areas has emphasized the effects of urban sprawl on mobility, transportation, and on energy efficiency (Johnson, 2001). These consequences are directly related to urban form and density (Johnson, 2001, Rubiera-Morollón & Garrido-Yserte, 2020). For instance, in Germany, buildings currently contribute as much as 30 % to the country's greenhouse gas emissions, considering both direct and indirect emissions. In terms of direct emissions alone, they account for 13 % (BMUB, 2016).

Energy consumption and urban mobility have been consistently emphasized in various reports' environmental sustainability criteria. In the Spatial Development Report of Switzerland (2005), two relevant criteria were highlighted:

- Spatial planning encourages the adoption of environmentally friendly modes of transportation and aims to reduce the need for excessive mobility among all sections of the population.
- The preference is given to utilizing existing buildings rather than constructing new ones. This saves high amounts of energy from being wasted (Federal Office for Spatial Development, 2005).

The indicators that Ameen et al. (2015) proposed for urban sustainability assessment include walking distances to urban open spaces, CO_2 emissions from transportation, and the use of local materials.

If we acknowledge that less sprawl equates to greater environmental sustainability, consider the following important example: Schwick et al. (2018) studied how various approaches to densifying residential areas and the existence of urban open areas such as parks impact the level of sprawl. They considered three scenarios for a given number of inhabitants: 1- without open-green spaces in the landscape; most of the neighborhood is covered by single family houses and the connecting roads, 2- half of the settlement area in scenario 1 was converted into green or open areas, 3- one-third of the settlement area in scenario 1 was converted into green or open areas. scenario 2 resulted in a remarkable 59% reduction in urban sprawl, while in scenario 3, the reduction amounted to 33%. These findings emphasize the importance of densification in urban planning to mitigate urban sprawl, challenging some of the warnings that densification would lead to less green space.

Biodiversity: There are worldwide efforts to enhance urban sustainability, as seen in initiatives like the New Urban Agenda by the United Nations (2020). This agenda highlights five essential dimensions for urban improvement, including environmental sustainability, which encompasses aspects like biodiversity conservation, climate change resilience, and mitigation. Biodiversity-friendly cities are closely tied to both sustainable urban growth and the well-being of their residents (Kowarik et al., 2020). Gagne and Fahrig (2010) studied the relationship between housing density, urban sprawl, and its impact on native biodiversity, particularly forest breeding birds in Ottawa and Gatineau, Canada. Their results indicate that increased housing density mitigates the adverse impacts of urbanization on these birds, as evidenced by their abundance, species richness, and evenness observed in different development scenarios.

In general, while the concept of sustainability may be somewhat elusive and deciding what is truly sustainable can be a complex task, identifying unsustainable and less sustainable behaviors is often more straightforward. For example, researchers widely agree that increased energy consumption and heavy reliance on fossil fuels are unsustainable (Hassan and Lee, 2015). Tab 3 outlines several outcomes of urban sprawl, extracted from the European report by EEA and FOEN (2016), which negatively impact the environmental sustainability of urban areas.

Table 3 - Environmental consequences of urban sprawl (Source: EEA & FOEN, 2016)

Consequence	Sources
Higher energy consumption per person and higher greenhouse gas emissions per person	Jones and Kammen (2014)
Higher pressure on protected areas	Haber (2007)
Increased risk of flooding (e.g. because of sealed surfaces)	Wilson and Chakraborty (2013)
The loss of habitats for native species and loss of biodiversity	Alberti (2005)
Increased temperatures leading to changes in microclimate conditions as a result of the urban heat island effect	Stone et al. (2010)
Increase in private car use	De Ridder et al. (2008)

3- Methods

This chapter describes the methods that will be applied to the case study of this research in order to measure the degree of urban sprawl. The study area and reporting units, the main components of urban sprawl, measurements, and tools, as well as information about data, scenarios, targets, and limits will be explained in this section.

3-1- Study Area and Reporting Units

Germany, a western European country with a land area of approximately 357,000 km^2, was home to around 82.79 million inhabitants in 2018 (BKG, 2019). The governance and administrative system in Germany operate within a federal framework, including the national level, states, regions, and local authorities (Fig. 7). The Federal Republic of Germany has 16 federal states and 111 planning regions which will be used as reporting units for this research. A reporting unit is the entity that the data are gathered from and for which the value of urban sprawl is determined. Depending on institutional structures, the legal framework for data collection, customs, priorities, and survey resources will differ from sector to sector and from state to state.

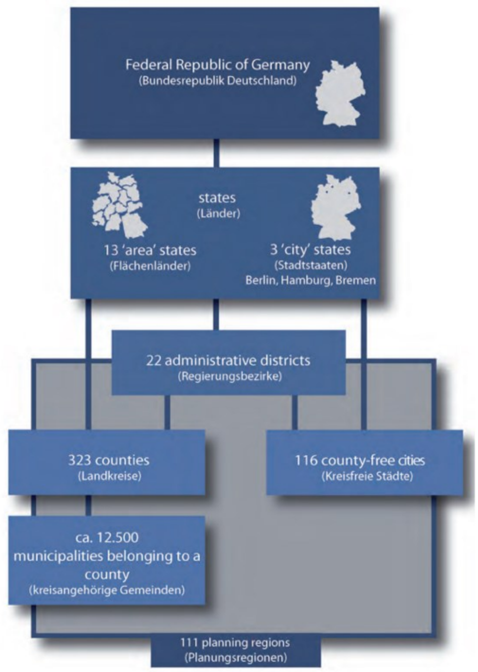

Figure 7- Administrative structure of Germany (source: Pahl-Weber & Dietrich Henckel, 2008)

3-1-1- Federal States of Germany

Germany is comprised of 16 federal states (Tab. 4 & Fig. 8), which include 13 "area states" and 3 "city states", where the cities themselves are considered states. The three city-states are Berlin, Hamburg, and Bremen. The objectives and principles established at the federal level serve as a foundational structure for the 16 states. These states, in response, outline their own spatial development objectives for state-wide and regional planning. This connection highlights the close relationship between the state and regional levels (Scharmann, 2020).

The states' structural policies are crucial for fostering spatial development and enhancing infrastructure measures in Germany. The Federal Spatial Planning Act mandates that states participate in state spatial planning. This involves the adoption of state spatial planning acts that align with the recommended guiding principles and spatial planning guidelines tailored to the specific conditions within each state. The planning process in the states, as outlined in the Spatial Planning Act, comprises two distinct phases. State spatial planning deals with overall spatial development within the state, while regional planning focuses on specific divisions within the state (Pahl-Weber & Dietrich Henckel, 2008).

Table 4 shows the codes and names along with their abbreviations assigned to each reporting unit utilized within the GIS software.

Table 4 - Federal States of Germany

Number	Federal States Name	Abbreviation	Area (km^2)
FS001	Schleswig-Holstein	SH	15804.2
FS002	Hamburg	Hh	750.8
FS003	Niedersachsen	Ni	47739.3
FS004	Bremen	Hb	412.1
FS005	Nordrhein-Westfalen	NW	34112.4
FS006	Hessen	He	21115.5
FS007	Rheinland-Pfalz	RP	19851.9
FS008	Baden-Württemberg	BW	35747.7
FS009	Bayern	By	70542.0
FS010	Saarland	Sl	2571.0
FS011	Berlin	Be	891.1
FS012	Brandenburg	Bb	29653.3
FS013	Mecklenburg-Vorpommern	MV	23280.8
FS014	Sachsen	Sn	18449.5
FS015	Sachsen-Anhalt	ST	20555.8
FS016	Thüringen	Th	16202.7

Figure 8 - Germany's federal states (source: BKG, 2019)

3-1-2- Planning Regions of Germany

There are 111 planning regions (Tab. 5 & Fig. 9) in force in the 16 Federal States in Germany. German regional planning is seen as a level of planning intermediate between the state and municipal levels. Hence, the territory covered by a regional plan, or the planning region, is a combination of counties and municipalities and a state. When it comes to defining planning regions, these pertain to regional planning zones located below the national level. They are typically characterized by the existence of a regional plan that is developed and updated as needed. In most federal states, planning regions consist of multiple districts and autonomous cities (Behnisch et al., 2022a).

The history of regional-scale planning can be traced back to Germany's planning framework, where municipalities in the Ruhr and Berlin metropolitan areas started to voluntarily organize themselves in the early 20th century (Siedentop et al., 2022). Planning regions are constituted in keeping with spatial planning needs. In theory, they should match the catchment area of a high-order center (as a particular characteristic), but in fact, they are the afflicted counties' or an administrative district's territory (Regierungsbezirk).

Planning regions are not administrative units of the federal government but instead serve as the spatial framework for observation and analysis in federal spatial planning (BBSR, n.d.). These regions help in understanding large-scale patterns such as urban growth, infrastructure distribution, regional disparities, and commuting flows.

In most federal states, planning regions are made up of several districts and district-free cities. In the federal state of Lower Saxony (Niedersachsen), regional planning authorities generally correspond to district boundaries. The only exception is PLR 039, Zweckverband Großraum Braunschweig, which encompasses several districts. the regional planning level is not applicable in the city-states of Berlin, Hamburg, and Bremen, as well as in the Saarland (Behnisch et al., 2022a). However, to maintain clarity in the results section and provide a comprehensive overview of whole Germany, these states are also included in the planning regions analysis.

In general, districts are either smaller than planning regions or similar to them. However, The three regions PLR 016, PLR 029, and PLR 042, “Landkreis Göttingen,” “Landkreis Osterode am Harz,” and “Stadt Göttingen,” respectively have been merged into a single district known as "Landkreis Göttingen". Since for future urban sprawl scenarios, the population and job data is available in district level and separating districts to smaller boundaries is not possible, PLR016 in results and discussion sections represents all PLR016, 029 and 042.

Table 5 presents the names, codes, and areas assigned to each reporting unit utilized within the GIS software.

Table 5 - Planning Regions of Germany

Number	**Planning Regions Name**	**Area (km^2)**	**Related Federal State**
PLR001	Planungsraum I (SH)	4209.7	SH
PLR002	Planungsraum II (SH)	3462.9	SH
PLR003	Planungsraum III (SH)	8139.5	SH
PLR004	Hamburg	750.9	Hh
PLR005	Bremen	412.1	Hb
PLR006	Grafschaft Bentheim	981.8	Ni

PLR007	Heidekreis	1881.4	Ni
PLR008	Landkreis Ammerland	730.5	Ni
PLR009	Landkreis Aurich	1294.5	Ni
PLR010	Landkreis Celle	1550.8	Ni
PLR011	Landkreis Cloppenburg	1420.4	Ni
PLR012	Landkreis Cuxhaven	2059.5	Ni
PLR013	Landkreis Diepholz	1991.0	Ni
PLR014	Landkreis Emsland	2883.7	Ni
PLR015	Landkreis Friesland	618.3	Ni
PLR016	Landkreis Göttingen	1001.6	Ni
PLR017	Landkreis Hameln-Pyrmont	797.5	Ni
PLR018	Landkreis Harburg	1248.6	Ni
PLR019	Landkreis Hildesheim	1208.3	Ni
PLR020	Landkreis Holzminden	694.3	Ni
PLR021	Landkreis Leer	1086.6	Ni
PLR022	Landkreis Lüchow-Dannenberg	1226.7	Ni
PLR023	Landkreis Lüneburg	1327.8	Ni
PLR024	Landkreis Nienburg (Weser)	1400.8	Ni
PLR025	Landkreis Northeim	1268.8	Ni
PLR026	Landkreis Oldenburg	1064.8	Ni
PLR027	Landkreis Osnabrück	2121.9	Ni
PLR028	Landkreis Osterholz	652.7	Ni
PLR029	Landkreis Osterode am Harz	636.8	Ni
PLR030	Landkreis Rotenburg (Wümme)	2074.7	Ni
PLR031	Landkreis Schaumburg	675.7	Ni
PLR032	Landkreis Stade	1266.9	Ni
PLR033	Landkreis Uelzen	1462.6	Ni
PLR034	Landkreis Vechta	814.2	Ni
PLR035	Landkreis Verden	789.4	Ni
PLR036	Landkreis Wesermarsch	827.7	Ni
PLR037	Landkreis Wittmund	659.0	Ni
PLR038	Region Hannover	2297.1	Ni
PLR039	Zweckverband Großraum Braunschweig	5093.2	Ni
PLR040	Stadt Delmenhorst	62.5	Ni
PLR041	Stadt Emden	112.4	Ni
PLR042	Stadt Göttingen	116.9	Ni
PLR043	Stadt Oldenburg (Oldb)	103.1	Ni
PLR044	Stadt Osnabrück	119.8	Ni
PLR045	Stadt Wilhelmshaven	106.9	Ni
PLR046	Regierungsbezirk Detmold	6525.2	NW
PLR047	Regierungsbezirk Köln	7364.0	NW

PLR048	Regionalverband Ruhr (RVR)	4438.7	NW
PLR049	Regierungsbezirk Arnsberg außerhalb RVR	6194.9	NW
PLR050	Regierungsbezirk Düsseldorf außerhalb RVR	3638.1	NW
PLR051	Regierungsbezirk Münster außerhalb RVR	5951.4	NW
PLR052	Planungsregion Nordhessen	8290.8	He
PLR053	Planungsregion Mittelhessen	5380.5	He
PLR054	Planungsregion Südhessen	6724.7	He
PLR055	Region Mittelrhein-Westerwald	6434.1	RP
PLR056	Region Rheinhessen-Nahe	2932.2	RP
PLR057	Region Rhein-Neckar	5636.5	RP
PLR058	Region Trier	4925.8	RP
PLR059	Region Westpfalz	3083.9	RP
PLR060	Saarland	2571.0	Sl
PLR061	Region Bodensee-Oberschwaben	3501.0	BW
PLR062	Region Donau-Iller	5464.6	BW
PLR063	Region Heilbronn-Franken	4764.9	BW
PLR064	Region Hochrhein-Bodensee	2755.9	BW
PLR065	Region MIttlerer Oberrhein	2137.1	BW
PLR066	Region Neckar-Alb	2529.1	BW
PLR067	Region Nordschwarzwald	2339.1	BW
PLR068	Region Ostwürttemberg	2138.3	BW
PLR069	Region Schwarzwald-Baar-Heuberg	2529.3	BW
PLR070	Region Stuttgart	3653.7	BW
PLR071	Region Südlicher Oberrhein	4071.3	BW
PLR072	Region Allgäu	3349.0	By
PLR073	Region Augsburg	4064.6	By
PLR074	Region Bayerischer Untermain	1477.2	By
PLR075	Region Donau-Wald	5688.7	By
PLR076	Region Ingolstadt	2847.6	By
PLR077	Region Landshut	3766.6	By
PLR078	Region Main-Rhön	3992.0	By
PLR079	Region München	5500.7	By
PLR080	Region Nürnberg	2934.2	By
PLR081	Region Oberfranken-Ost	3616.4	By
PLR082	Region Oberfranken-West	3675.4	By
PLR083	Region Oberland	3955.7	By
PLR084	Region Oberpfalz-Nord	5292.8	By
PLR085	Region Regensburg	5207.7	By
PLR086	Region Südostoberbayern	5225.0	By

PLR087	Region Westmittelfranken	4309.8	By
PLR088	Region Würzburg	3060.9	By
PLR089	Berlin	891.1	Be
PLR090	Region Havelland-Fläming	6841.4	Bb
PLR091	Region Lausitz-Spreewald	7219.7	Bb
PLR092	RegionOderland-Spree	4563.0	Bb
PLR093	Region Prignitz-Oberhavel	6473.2	Bb
PLR094	Region Uckermark-Barnim	4556.1	Bb
PLR095	Region Mecklenburgische Seenplatte	5495.1	MV
PLR096	Region Rostock	3610.8	MV
PLR097	Region Vorpommern	7152.0	MV
PLR098	Region Westmecklenburg	7022.1	MV
PLR099	Region Chemnitz	6527.7	Sn
PLR100	Region Leipzig-Westsachsen	3977.8	Sn
PLR101	Region Oberes Elbtal/Osterzgebirge	3437.3	Sn
PLR102	Region Oberlausitz-Niederschlesien	4506.7	Sn
PLR103	Region Altmark	4741.7	St
PLR104	Region Magdeburg	5601.4	St
PLR105	Planungsregion Anhalt-Bitterfeld-Wittenberg	3650.1	St
PLR106	Planungsregion Halle	3727.6	St
PLR107	Planungsregion Harz	2834.9	St
PLR108	Planungsregion Nordthüringen	3674.5	Th
PLR109	Planungsregion Mittelthüringen	3745.6	Th
PLR110	Planungsregion Ostthüringen	4684.9	Th
PLR111	Planungsregion Südwestthüringen	4097.7	Th

Figure 9 - Germany's 111 Planning Regions (source: BKG, 2019; Behnisch et al., 2022a)

3-2- Measurement of urban sprawl

3-2-1- Weighted Urban Proliferation (*WUP*)

Weighted Urban Proliferation (*WUP*) is a metric for investigating and evaluating the degree of urban sprawl (Jaeger & Schwick, 2014). This method is based on the urban permeation (*UP*) method developed by Jaeger et al. (2010b), which was initially introduced along with a few related measures, such as total sprawl (*TS*) and sprawl per capita (*SPC*). The *WUP* metric combines three components:

1- **Percentage of built-up areas (*PBA*):** This component calculates the ratio of the size of built-up areas to the size of the reporting unit. A higher *PBA* denotes larger urban areas and hence more urban sprawl. The formula below shows how to calculate *PBA*.

$$PBA = {A_{\text{built-up}}}/{A_{\text{reporting unit}}}$$

A indicates Area.

2- **Dispersion of the built-up areas (*DIS*):** This component calculates the level of scatteredness of the built-up area throughout the landscape. More scattered urban growth is indicated by a higher *DIS*. It calculates the distances between any two points in the urban areas and is based on the average effort required to provide services from all urban points, such as buildings, to random delivery points within a specific analysis scale known as the Horizon of Perception (*HP*) or cut-off radius. According to Jaeger et al. (2010b), if a person's eye height is 180 cm and there are no obstructions blocking their view, they can see an area within a 4.9 km radius due to the curvature of the Earth. As a result, a distance range of 1 km to 10 km is generally suitable in most cases. The *HP* used in this study is 2 km in accordance with EEA & FOEN (2016). Built-up area pixels outside Germany's official border but still within the *HP* are not cut off.

3- **Land uptake per person (*LUP*):** This component describes the use of built-up area by people (inhabitants and jobs) working and living in that area.

$$LUP = {1}/{UD} = {A_{\text{built-up}}}/{N_{\text{inh+job}}}$$

UD is utilization density and measures the number of residents or jobs occupying the built-up areas within the specified reporting units.

WUP is calculated with the following formula:

$$WUP = (PBA \times DIS) \times \mathrm{w}_1(DIS) \times \mathrm{w}_2(LUP)\,,$$

$w_1(DIS)$ and $w_2(LUP)$ are weighting functions for dispersion and land uptake per person, respectively. *WUP* is expressed in urban permeation units per m^2 of land (UPU/m^2).

WUP is also measured with the following formula:

$$WUP = UP \times \mathrm{w}_1(DIS) \times \mathrm{w}_2(LUP).$$

In this case, *UP* stands for Urban Permeation. Jaeger et al. (2010b) defined *UP* as a measure of how extensively an urban area has permeated the surrounding landscape, and it is quantified in urban permeation units per square meter of landscape (UPU/m^2):

$$UP = PBA \times DIS.$$

3-2-2- Sprawl Per Capita (*SPC*) and Weighted Sprawl Per Capita (*WSPC*)

SPC or Sprawl per capita is generated by dividing Total Sprawl (*TS*) by the number of people who live (inhabitants) or work in the reporting unit (Jaeger et al., 2010b):

$$SPC = {}^{TS}/_{N_{\text{inh+job}}}.$$

The value of *WUP* measures the extent of sprawl within a given land area, whereas *WSPC* quantifies the average degree of urban sprawl associated with each resident or job in the reporting unit (Behnisch et al., 2022b). *WSPC* is calculated through the following formula:

$$WSPC = \mathrm{w}_1(DIS) \times \mathrm{w}_2(LUP) \times SPC.$$

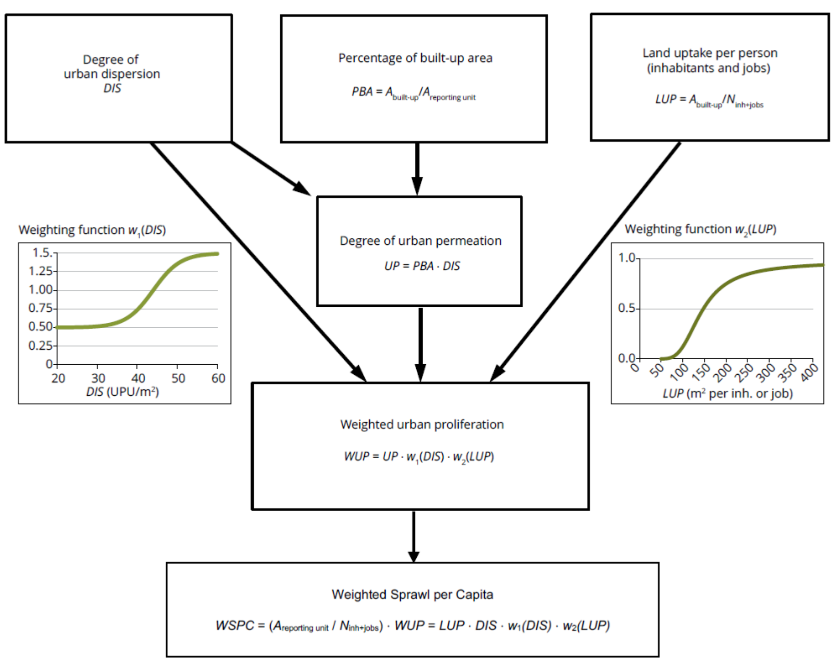

Figure 10-The relationships between WUP, WSPC, and their components DIS, PBA, and LUP (Source: EEA & FOEN, 2016; Pourali et al., 2022)

3-2-3- Total Sprawl *(TS)*

If we think about dispersion (*DIS*) as the average "effort" needed to connect two random urban points while staying within the area we can perceive (distance < *HP*), total sprawl (*TS*) would represent the overall average "effort" required to connect every point to a different random point inside the initial point's horizon of perception. Based on this explanation, the value of this measure consistently rises as the amount of developed built-up areas increases within the reporting unit (Jaeger et al., 2010b). For measuring *TS*, we use the following equation:

$$TS = DIS \times A_{\text{built-up}}.$$

3-2-4- The Urban Sprawl Metrics (USM) Toolset

To simplify and speed up the calculation of *WUP* and its components in the designated reporting area, the Urban Sprawl Metrics (USM) toolset was created (Nazarnia et al., 2023). The USM toolset is a software tool created using programming languages like Python and C+. It is a geographic information system (GIS) toolset that is freely available for download. It can be found on the Swiss Federal Institute of Forest, Snow and Landscape Research (WSL) homepage (www.wsl.ch/zersiedelung) and on Spectrum, Concordia University's open access research repository. The main steps to effectively use the USM Toolset are (Nazarnia et al., 2023):

1. Prepare the necessary input data and create two working folders: a 'Directory' folder and an 'Output' folder.
2. In the 'Directory' folder, store the input data required for the analysis. Three inputs are needed for the calculations in the USM toolset: 1) the binary map of built-up areas (raster format), 2) the geodatabase feature class or shapefile of the reporting unit(s)/ area of study, and 3) the $S_i$values.exe file.
3. Ensure that the 'Output' folder is empty as it will be automatically populated with the output files generated during the calculations.

3-3- Data

Land-cover and land-use datasets are essential for running the model and examining the patterns of changes in land use and land cover. Specifically, for this particular study, the maps depicting the built-up areas, reporting units, as well as population and job data are necessary requirement. five sets of datasets were used for this research:

1- Two input data; one containing the geometry and administrative boundaries of Germany's 16 federal states, and the other containing the geometry and administrative boundaries of its 111 planning regions. These datasets were provided in vector format and have been compiled from the "VG25" dataset of the Federal Agency for Cartography and Geodesy (*BKG*). Behnisch et al. (2022a) utilized this dataset for their research, and it is the version I adopted for my work.

2- The built-up area maps were obtained from the World Settlement Footprint (*WSF*) Evolution dataset. This dataset offers annual observations with a high spatial resolution of 30 meters. The fine resolution allows for a precise analysis of urban sprawl and settlement changes over time. This dataset was generated by processing an extensive collection of seven million images from the US Landsat satellites, capturing the worldwide growth of human settlements on a year-by-year basis between 1985 and 2015. Moreover, for numerical calculation of *WUP* and finding the degree of dispersion, the values of S_i for each cell i in the landscape that the reporting units of interest are embedded in, are needed. The raster map of S_i values was computed by my colleagues at IOER, Dr. Tobias Krüger and Dr. Martin Behnisch from the *WSF* evaluation data.

3- Germany's population data from 1995 to 2015 was sourced from the Federal Institute for Building, Urban Affairs, and Spatial Research (BBSR). In general, population figures originate from the *Bevölkerungsfortschreibung* (annual population update) conducted by the statistical offices. The data, available at the municipal level, is based on the 1987 and 2011 Census and has been continuously updated using demographic statistics, including births, deaths, and migration trends. As of now, this dataset provides the most recent population figures, reflecting numbers as of December 31, 2023.

4- Germany's employment data covering the period from 1995 to 2015 were obtained from the Federal Institute for Building, Urban Affairs, and Spatial Research (BBSR). This dataset represents an extract from the BBSR's own database, which compiles employment statistics at the district level from 1995 to 2023 and is collected from official governmental sources (such as federal statistical office and federal employment agency). The dataset includes two main categories of employees: those subject to social security contributions (*svjobs*) and low-paid or short-term employees (*minijobs*). In both categories, individuals working at least one hour per week are included; however, detailed information specifically regarding part-time employment is not available. Certain employment groups are explicitly excluded from this dataset, including civil servants, self-employed individuals, family caregivers, professional and temporary soldiers, as well as individuals performing military or civilian service. More information regarding job data is provided in Appendix A.

5- For determining targets and limits of urban sprawl, future population and employment scenarios are needed. In this study, I utilize comprehensive projections from Institut für Arbeitsmarkt- und Berufsforschung (*IAB*), known in English as the Institute for Employment Research of the Federal Employment Agency in collaboration with the Bundesinstitut für Berufsbildung (*BIBB*) or Federal Institute for Vocational Education and Training, which provide detailed insights into future demographic and employment trends across Germany. They are part of the broader QuBe (Qualifications and Occupational Field Projections) Baseline Projection**.** The population projection extends to the year 2040, offering updated demographic figures for the 401 districts and independent cities in Germany. This projection is distinct in its detailed differentiation by age, gender, and nationality, separating individuals with German citizenship from non-Germans. Such differentiation reflects significant variations in birth rates and migration behaviors between these groups. The employment projections are at the district level and extend up to the year 2040. Since I do not have access to inhabitant and employment projections for 2040–2050, a linear extrapolation approach was used for the final ten years, based on the last ten years of the QuBe dataset, to align with the objectives of this study. Since the reporting units of this study are planning regions and federal states, projections for these two levels were generated by aggregating district-level data based on their corresponding IDs.

3-4- Future Scenarios

In this study, 5 scenarios are proposed to form a reference framework for defining the targets and limits for urban sprawl. These scenarios demonstrate various possible development paths by changing a variable in each of them while keeping the others constant for the target year. Schwick et al. (2015) used a rather similar method for Switzerland. They presented six scenarios of urban sprawl for Switzerland (Fig. 13).

The base year for the scenarios is 2015, as it is the most recent year for which built-up area data is available. The target year is set to 2050, which I consider a reasonable choice for several reasons. First, it provides a 25-year time span (from now), allowing for medium to long-term planning. It is not too far in the future, where the uncertainty of socio-economic changes could make projections unreliable. At the same time, it is not too short, which ensures that the proposed policies or planning measures have enough time to be implemented. Additionally, the availability of projected population and employment data only extends to 2040, which further limits how far into the future the scenarios can go.

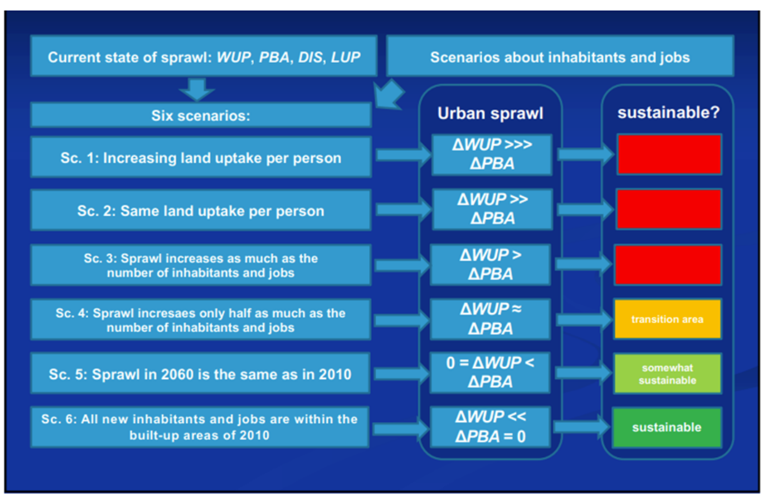

Figure 11-Scenarios for determining targets and limits for urban sprawl (source: Schwick et al., 2018)

3-4-1- Scenario 1 - Business as usual

In this scenario, *LUP* continues to increase in line with the trend observed in each planning region (PLR) or state. This increase is based on the observed rise in built-up areas per inhabitant or job over the 20-year period between 1995 and 2015. Given the estimated population and job data from 2015 to 2050, and *LUP*, the corresponding built-up area for each year i can be calculated using the following formula:

$$\text{Built-up area}_i\ (\text{m}^2) = LUP_i \left[\frac{\text{m}^2}{\text{inhabitants and jobs}}\right] \times N_{\text{inhabitants and jobs}_i}$$

The *PBA* can be calculated by dividing the total built-up area by the total area of the reporting unit. To estimate potential dispersion for the future, *DIS* is calculated as a function of *PBA*. To determine if a meaningful relationship exists between dispersion and the percentage of built-up area, all 111 data points (representing the planning regions in 2015) were plotted with *PBA* on the X-axis and *DIS* on the Y-axis. The trend line for the points appears to follow a logarithmic relationship (Fig. 12).

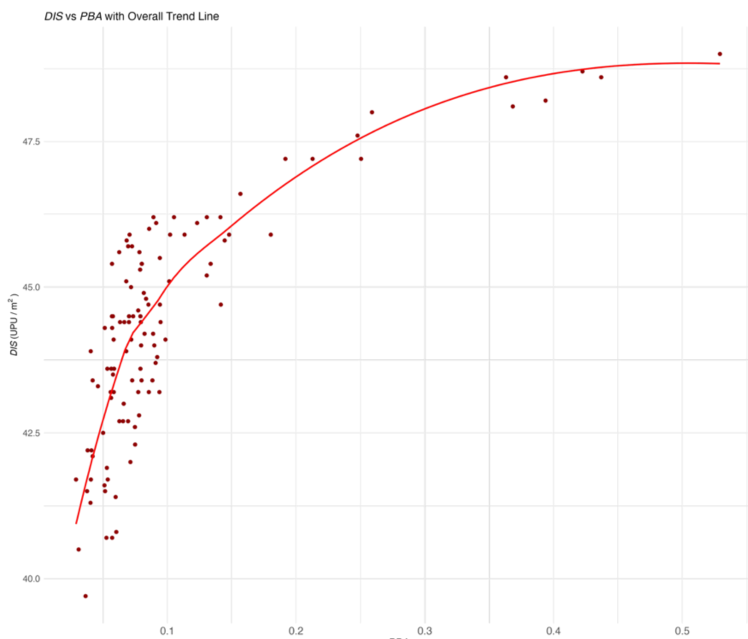

Figure 12 - Value of DIS as a function of PBA in 2015 across planning regions of Germany

Various statistical tests were conducted, including linear, quadratic, logarithmic, and log-log models. The logarithmic model demonstrated the highest R-squared and adjusted R-squared values (Tab. 6).

Table 6 - Statistical tests result for the relationship between PBA and DIS across Germany's planning regions

Model	R-squared	Adjusted R-squared	Residual Standard Error	F-statistic	Significance (*p*-value)
Quadratic	0.6693	0.6632	1.133	109.3	< 2e-16
Logarithmic	0.7021	0.6993	1.07	256.9	< 2.2e-16
Log-Log	0.6865	0.6836	0.02474	238	< 2.2e-16
Cubic	0.6957	0.6872	1.092	81.55	< 2.2e-16

The equation below represents the logarithmic relationship between *DIS* and *PBA*:

$$DIS_{\text{general},\, i} = 51.4462\ (\text{UPU/m}^2) + 2.8582\ (\text{UPU/m}^2) \cdot \log(PBA), \quad 0 < PBA < 1$$

Since there are noticeable intercepts in some cases—where multiple PLRs share the same *PBA* but exhibit different *DIS* values—a modification was applied to the general formula. This adjustment aimed to improve the accuracy of the estimates of *DIS* for the year 2050, recognizing that *DIS* can vary substantially across different PLRs. To account for these differences, the formula was customized for each PLR by adjusting the intercept based on its specific *PBA* and *DIS* values from 2015. This adjustment involves calculating a residual, defined as:

$$\text{Residual}_{\text{PLR},\, i} = DIS_{\text{actual, 2015}} - DIS_{\text{general, 2015}}$$

Therefore, the final equation for estimating *DIS* in a future year *i* is:

$$DIS_{\text{adjusted},\, i} = 51.4462\,(\text{UPU/m}^2) + 2.8582\,(\text{UPU/m}^2) \cdot \log(PBA) + \text{Residual}_{\text{PLR}j}, \quad 0 < PBA < 1$$

With the same approach the relationship between *PBA* and *DIS* at federal level was estimated. The details are provided in Appendix B.

3-4-2- Scenario 2 – Constant *LUP*

In this scenario, *LUP* remains at the value as it was in the base year. The calculation of sprawl metrics in this scenario follows the same approach as in scenario 1.

3-4-3- Scenario 3 - *WUP* mirrors population and employment trends

In this scenario, urban sprawl changes proportionally to the number of inhabitants and jobs (i.e., the same relative increase or decrease). For finding the *WUP* value in a future year_i, the following equation is used:

$$WUP_i = WUP_{2015} \times \left(\frac{N_{\text{inhabitants and jobs}, i}}{N_{\text{inhabitants and jobs}, 2015}} \right)$$

By using the projected number of inhabitants and jobs, along with WUP_{2015}, I estimated future *WUP* values. Given these estimated values of *WUP*, and considering that *DIS* is a function of *PBA*, and *LUP* is also dependent on *PBA*, an iterative process was used to solve for the values of *PBA*, *LUP*, and *DIS*. This process involves adjusting the *PBA* value iteratively until the estimated *WUP* closely matches the calculated *WUP* within a predefined numerical tolerance. The implementation uses a While-loop structure in R, where for each planning region and year, the value of *PBA* is updated step-by-step. Once *PBA* converges, the corresponding *DIS* and *LUP* values are calculated using the calibrated model equations. The calculation loop stops when the absolute difference between the estimated and actual *WUP* is less than predefined tolerance.

3-4-4- Scenario 4 – Constant urban sprawl

In this scenario, urban sprawl in the target year (2050) remains the same as in the base year (2015). This means that, regardless of population growth or decline, there is no increase in the *WUP* value. The method for calculating *PBA*, *DIS*, and *LUP* is the same as in scenario 3.

3-4-5- Scenario 5A- Densification in states or regions with growing population

In this scenario, all new inhabitants will reside within the built-up areas that already existed in 2015 in the planning regions (or federal states) with increasing population and jobs. For scenario 5A, only planning regions with a positive population-job change were considered. In this scenario, the values of *PBA* and *DIS* in 2050 remain the same as their 2015 levels. *LUP* is calculated based on the projected number of inhabitants and jobs, and *WUP* is then estimated accordingly.

3-4-6- Scenario 5B- Densification in states or regions with shrinking population

In this scenario, the built-up area in shrinking regions (or states) decreases. The changes in population and job numbers between 2015 and 2050 were calculated first, and for regions with negative population growth, the built-up area was reduced by 1.25 times the percentage reduction

in population and jobs. Given the values of built-up area and the projected number of inhabitants and jobs, the values of *PBA*, *DIS*, *LUP*, and *WUP* are calculated accordingly.
After detailed consideration of each scenario, we can decide about suitable targets, limits, and warning values.

3-5- Targets and Limits

Setting reference values such as targets and limits to control urban sprawl is crucial for managing scarce resources and future urban growth development (Hersperger et al., 2017). Initially, we require definitions for three kinds of reference values:

- A limit value is a legal standard that must not be surpassed. Although this value is neither a standard nor a legally binding criteria, it often has some legal aspects (European Community EC, 2002).
- A target value is an aspired benchmark, occasionally also referred to as a guide value or recommended value.
- A warning value (or alarm value) is a level where action needs to be taken urgently to avoid getting further away from the limit.

In addition to these reference values, "no deterioration" signifies the level of urban sprawl recorded at a specific reference point in time, which should not be exceeded. In other words, the no deterioration condition corresponds to scenario 4, in which the level of urban sprawl in the target year remains equal to that of the base year.

Although limiting urban sprawl is challenging, other environmental areas have successfully addressed similar issues through the establishment of targets and limits as explained in literature review. Defining reference values for urban sprawl presents a more complicated challenge. Unlike air quality guidelines, which focus on specific pollutants and their health impacts, determining an absolute level of tolerable urban sprawl is scientifically complex. Urban sprawl's ecological, social, and economic consequences are multifaceted and often not easily quantifiable, further complicated by potential time delays in their manifestation. However, while precise reference values for urban sprawl may be elusive, certain extreme conditions, such as severe limitations on agricultural land availability, are universally recognized as unsustainable.

Moreover, unlike air quality guidelines, which are primarily rooted in scientific evidence, reference values for urban sprawl are shaped by a multitude of factors, including societal needs, political considerations, and environmental sustainability goals. Consequently, these values emerge from a nuanced negotiation process that balances various objectives and requirements within a social and political context (Mosharafian, 2023).

Targets and limits for urban sprawl can be determined using the *WUP* approach. These values can be based on how much the population grows, as demonstrated in a project led by Schwick et al. (2018) for Switzerland and a similar project by Mosharafian (2023) for Montreal. Targets and limits can be set according to regions, in order to consider differences in natural conditions and their historic and socio-economic development. The specific thresholds for these values may vary based on the unique planning procedures and rules within each country. The main questions for setting targets and limits are: What further development of urban sprawl do we want to accept? What do we consider sustainable? In which landscapes do we want to live in the future?

For answering these questions, we start from the current level of urban sprawl in 2015 and consider the scenarios for future development. The comparison of five scenarios for the year 2050 provides the foundation for establishing and rationalizing the targets and limits for Germany (Schwick et al., 2018; Mosharafian, 2023).

To ensure sustainability, the established targets and limits must be stricter than the anticipated urban sprawl values in less sustainable scenarios (such as scenario 1); in other words, they should be set at lower levels. The proposed approach recommends that the target be more ambitious than the value represented by scenario 4, which reflects a "no deterioration" condition. However, a uniform approach to defining urban sprawl targets and limits across Germany's planning regions and federal states is not feasible, as population trends vary significantly. Given the strong influence of population change on WUP, the reporting units are categorized into two groups, following the structure of scenarios 5A and 5B. For regions with increasing population ($P2050 - P2015 > 0$), scenario 5A is used as the target. For regions with declining population ($P2050 - P2015 < 0$), scenario 5B serves as the target value. For setting the limit, it is recommended to use a value that lies between the target and the “no deterioration” area (scenario 4). As for the warning value, the recommendation is to set it at a level situated a bit more than "no deterioration" value (scenario 4) but still within a range that does not represent highly unsustainable conditions.

4- Results

4-1- Urban sprawl trends at the national level

Urban sprawl in Germany increased consistently between 1995 and 2015. *WUP* rose by 51.67%, from 2.207 UPU/m² in 1995 to 3.348 UPU/m² in 2015. Between 2010 and 2015, the slope of increase became even steeper than in previous years (Tab. 7).

The components of urban sprawl showed similar trends during this period. *PBA* increased from 6.38% in 1995 to 8.37% in 2015, a +1.98 percentage point increase (+31.11% relative change). *LUP* grew from 207.6 m² to 253.9 m² (+22.31%), and *DIS* increased gradually from 44.219 to 44.702 UPU/m². Finally, *WSPC* experienced a notable rise, from 7178.1 to 10168.7 UPU/(inh. or job), marking a +41.48% increase (Tab. 7, Fig. 13, & Tab. D-1 in appendix D). In contrast, the number of inhabitants and jobs increased by 7.2%, highlighting a disproportionate growth in urban sprawl per capita.

Table 7 - Urban sprawl metrics in three points in time (1995-2015) across Germany

	WUP (UPU/m^2)			*LUP* (m^2/(inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
Country	**1995**	**2005**	**2015**	**1995**	**2005**	**2015**	**1995**	**2005**	**2015**	**1995**	**2005**	**2015**
Germany	2.207	2.747	3.348	207.6	230.6	253.9	6.381	7.308	8.366	7187.1	8670	10168.7

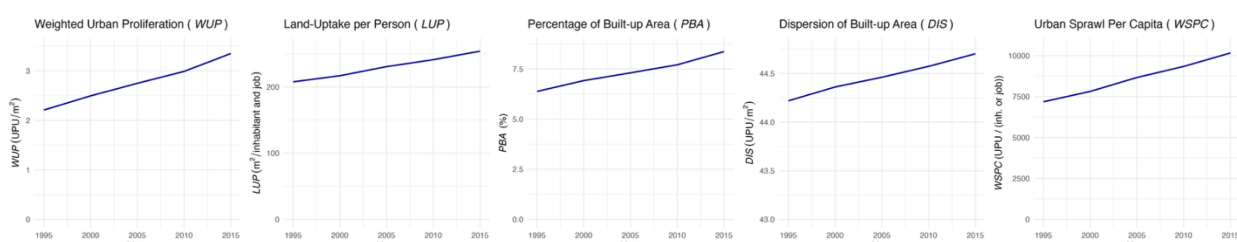

Figure 13 – Values of urban sprawl metrics between 1995 to 2015 in Germany

4-2- Urban sprawl trends at the federal level

Across Germany, urban sprawl metrics generally show a clear upward trend over the 20-year period (Tab. 8). *WUP* increased on average by 1.39 UPU/m² across the federal states. Most states experienced a steady rise, with the exception of Berlin and Hamburg. In Berlin, *WUP* began to decline after 2005, while in Hamburg, it slightly decreased between 2005 and 2010, followed by an upward trend again (Fig. 14). Bremen recorded the largest increase in *WUP*, rising from 8.6 to 13.6 UPU/m², whereas Mecklenburg-Vorpommern showed the smallest increase, from 0.83 to 1.32 UPU/m².

PBA rose in all federal states, with an average increase of 2.74 percentage points. Bremen recorded the highest increase at 6.68 percentage points, while Sachsen-Anhalt had the smallest increase at 1.12 percentage points (Fig. 15).

LUP followed an upward trend in most states, with an average increase of 61 m²/ (inh. or job), or +25.68%. However, In Berlin, *LUP* decreased by 4.7 m²/ (inh. or job) after 2005, and in Hamburg, *LUP* value fluctuated slightly but remained more or less stable overall (Fig. 16).

DIS showed an upward trend across the federal states, with an average increase of 0.48 UPU/m², or +1.12%. In Berlin, *DIS* increased slightly from 48.937 to 48.955—an increase of just 0.018 UPU/m²—while Baden-Württemberg experienced the largest increase, rising from 42.935 UPU/m² to 43.721 UPU/m², a difference of 0.789 UPU/m² (Fig. 17 & Tab. D-1 in appendix D).

WSPC showed a general upward trend, with an average increase by 3,322 UPU/ (inh. or job), equivalent to +47.79%. However, Hamburg experienced a decrease between 2005 and 2010, and in Berlin, the *WSPC* trend was consistently downward after 2005 (Fig. 18).

Table 8 - Urban sprawl metrics in three points in time (1995-2015) across Germany's federal states

	WUP (UPU/m²)			*LUP* (m²/(inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
Federal States	**1995**	**2005**	**2015**	**1995**	**2005**	**2015**	**1995**	**2005**	**2015**	**1995**	**2005**	**2015**
Baden-Württemberg	2.034	2.516	3.193	185.9	195.9	213.4	7.310	8.290	9.518	5173	5945	7158
Bayern	2.078	2.527	3.103	250.1	268.0	289.8	5.759	6.636	7.724	9022	10206	11642
Berlin	2.095	3.849	3.06	90.5	99.4	94.7	47.984	50.68	52.916	395	755	548
Brandenburg	1.269	1.536	1.811	329.6	388.5	439.6	3.838	4.391	5.015	10892	13586	15876
Bremen	8.599	11.703	13.655	138.4	151.8	157.4	32.694	36.143	39.373	3641	4915	5460
Hamburg	4.379	5.612	5.901	109.7	113.8	113.1	35.968	39.144	42.239	1335	1632	1579
Hessen	1.980	2.449	2.984	184.9	198.7	213.1	7.136	8.032	9.047	5130	6059	7029

Mecklenburg-Vorpommern	0.830	1.080	1.327	272.9	351.1	420.5	2.894	3.426	4.029	7824	11069	13849
Niedersachsen	1.965	2.556	3.178	244.9	278.2	314.0	5.223	6.294	7.382	9217	11297	13516
Nordrhein-Westfalen	3.711	4.618	5.740	165.6	177.7	193.8	11.524	12.927	14.494	5332	6347	7676
Rheinland-Pfalz	2.287	2.787	3.344	253.5	275.2	302.3	6.581	7.562	8.624	8808	10141	11724
Saarland	4.569	5.404	6.636	209.6	228.1	263.9	11.667	12.971	14.799	8209	9502	11834
Sachsen	1.759	2.405	3.178	228	261.5	311.1	4.397	5.556	6.839	9121	11321	14454
Sachsen-Anhalt	1.598	1.8839	2.1732	289.7	359.8	420.5	5.222	5.733	6.345	8863	11822	14402
Schleswig-Holstein	1.9304	2.482	3.1911	232.4	260.8	299.1	5.209	6.226	7.471	8611	10399	12775
Thüringen	1.3565	1.7756	2.1675	227.3	285.0	336.7	4.758	5.511	6.316	6479	9184	11555

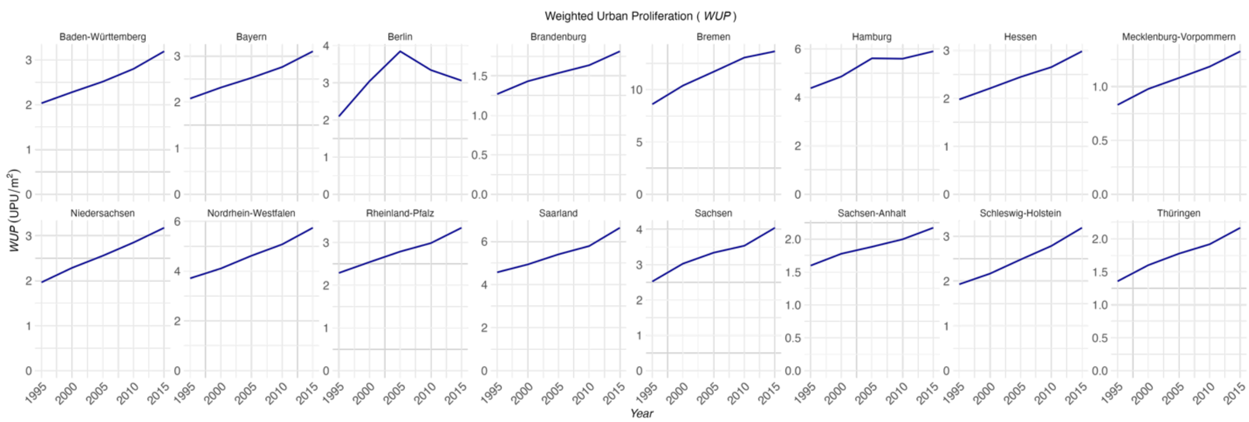

Figure 14 - WUP between 1995 to 2015 across all federal states of Germany

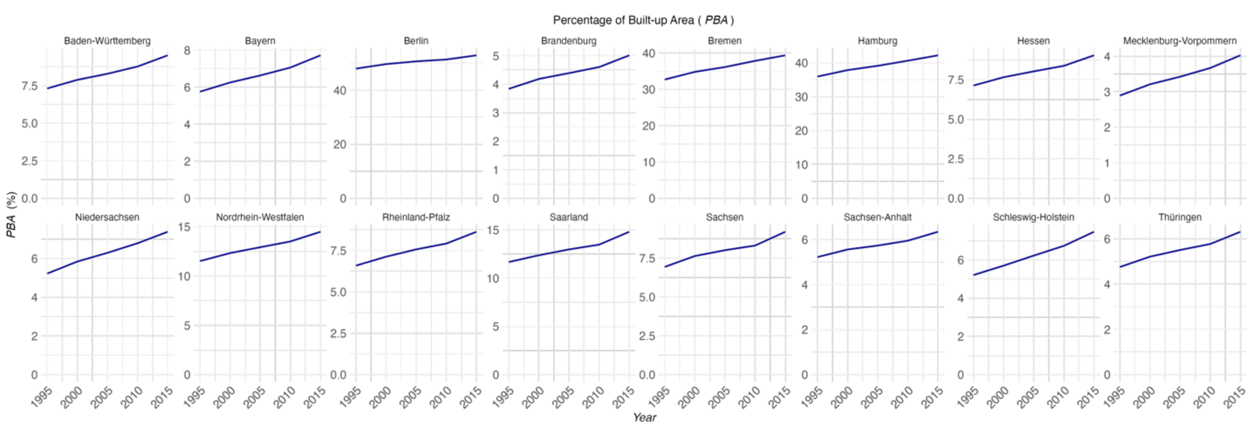

Figure 15 - PBA between 1995 to 2015 across all federal states of Germany

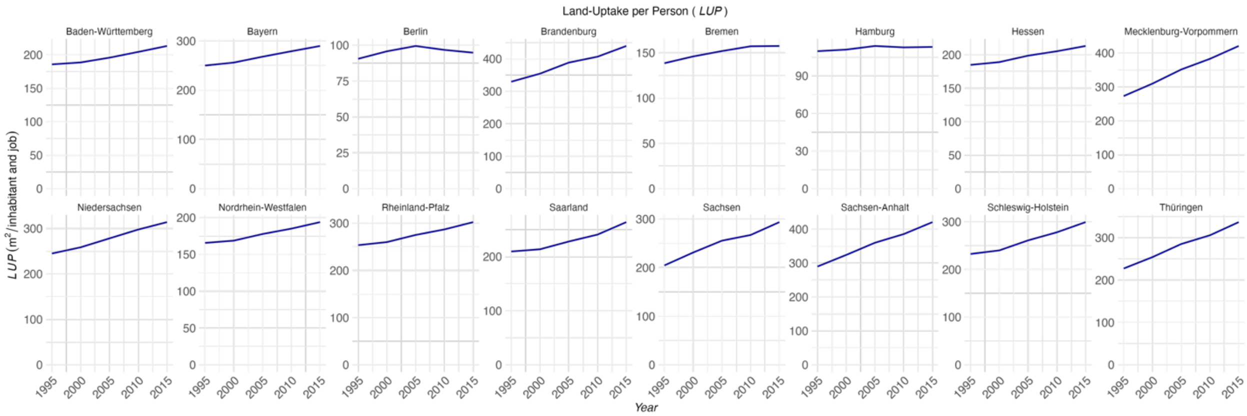

Figure 16 - LUP between 1995 to 2015 across all federal states of Germany

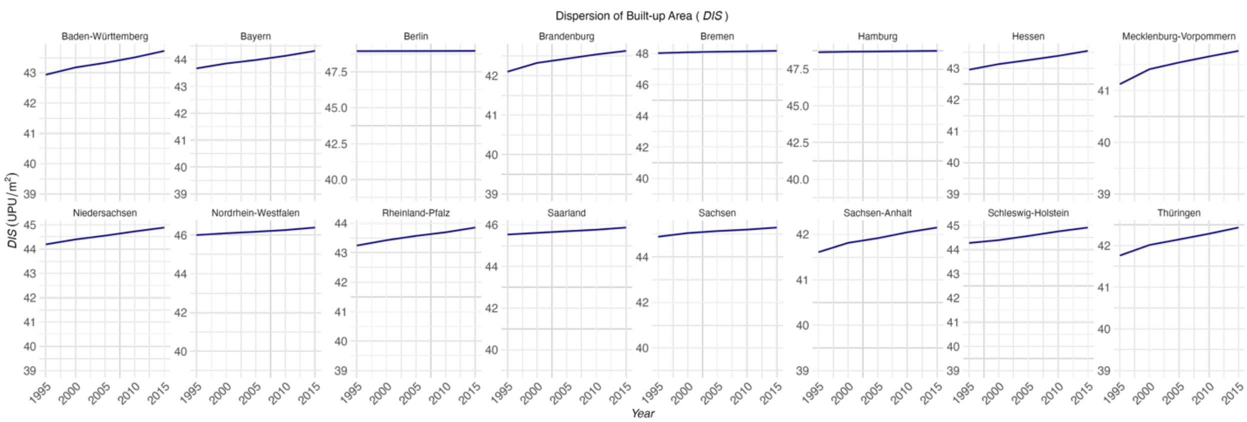

Figure 17 - DIS between 1995 to 2015 across all federal states of Germany

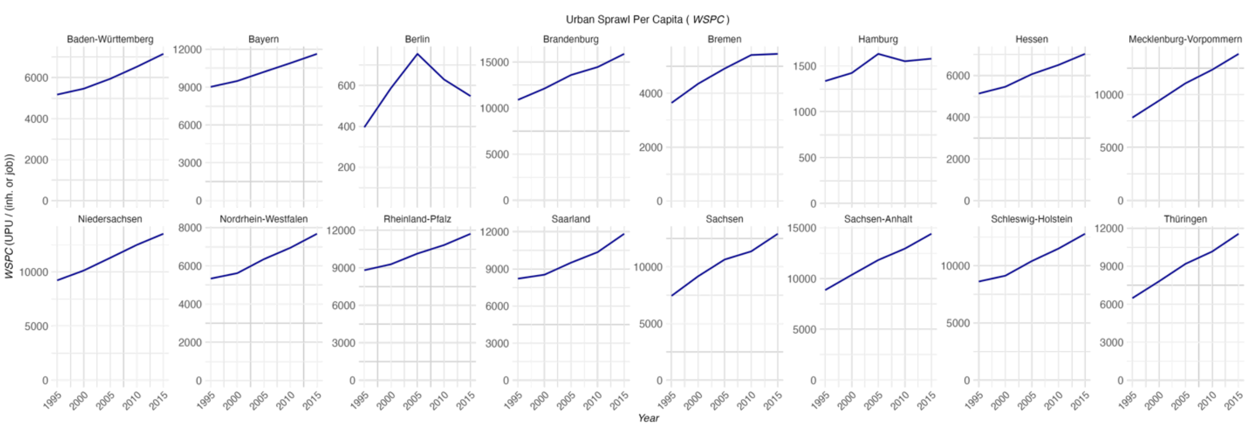

Figure 18 - WSPC between 1995 to 2015 across all federal states of Germany

4-3- Analyzing urban sprawl trends at the regional level

Similar to the trend observed in Germany's federal states, urban sprawl metrics at the regional level show a clear upward trend over the 20-year period (Tab. 9). *WUP* increased on average by 1.28 UPU/m², corresponding to a 56.5% rise. PLR005 (Bremen) experienced the biggest increase (5.06 UPU/m²), and PLR103 (Region Altmark) experienced the smallest increase in *WUP*, with just a 0.252 UPU/m² rise. The only regions that experienced some periodic decline in *WUP* are PLR089 (Berlin), in which *WUP* started to decrease from 2005, and PLR004 (Hamburg) in which *WUP* decreased slightly between 2005 and 2010 but it again started to increase (Fig. 19).

According to the box plot shown below, around eight regions fall above the average level of urban sprawl in each year (Fig. 24). These regions consistently showed higher *WUP* values between 1995 and 2015. PLR005, 040, 041, 043, 044, 045, 048, and 050 are among them. Most of these regions are highly urbanized, exhibiting elevated levels of *PBA*, *DIS*, and *WUP*. For instance, Bremen (PLR005) is one of Germany's city-states, meaning it is simultaneously a city, a region, and a federal state. By 2015, the average values of these three components across the eight regions were 12.67 UPU/m² (*WUP*), 30.95% (*PBA*), and 47.88 UPU/m² (*DIS*). In comparison, the national averages in Germany for the same year were 3.762 UPU/m², 10.1%, and 44.373 UPU/m², respectively.

PBA rose by an average of 2.31 percentage point. Across all PLRs, *PBA* shows an upward trend without exception. The largest increase between 1995 and 2015 was for PLR043 (Stadt Oldenburg), with an 8.745 percentage point increase, and the smallest increase in *PBA* was in PLR103 with a modest 0.662 percentage point rise (Fig. 20).

LUP increased by an average of 74.9 m²/ (inh. or job), or 28.3%. Three PLRs do not follow the overall trend: PLR004, PLR089, and PLR079, which are Hamburg, Berlin, and München respectively. *LUP* in PLR004 and PLR079 does not change much over the years and fluctuates, while in PLR089 *LUP* starts to decrease after 2005 (Fig. 21).

DIS showed a rather steady increase across all PLRs, with an average rise of 0.62 UPU/m², equivalent to approximately 1.4%. PLR037 (Landkreis Wittmund) experienced the largest increase in *DIS* (1.578 UPU/m²), and PLR089 (Berlin) saw the smallest increase of just 0.018 UPU/m² (Fig. 22 & Tab. D-2 in appendix D).

WSPC increased by 4,109.8 UPU/ (inh. or job), or 47.7% on average. While in most of the PLRs there's a clear upward trend between 1995 and 2015, in a few PLRs, *WSPC* did not change much or periodically decreased. For instance, in PLR079 (München), there are small decreases and increases over the years; in PLR004 (Hamburg), there is a decrease between 2005 and 2010; and in Berlin, the *WSPC* trend is downward after 2005 (Fig. 23).

Table 9 - Urban sprawl metrics in three points in time (1995-2015) across Germany's planning regions

	WUP (UPU/m^2)			*LUP* (m^2/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
PLR	**1995**	**2005**	**2015**	**1995**	**2005**	**2015**	**1995**	**2005**	**2015**	**1995**	**2005**	**2015**
PLR001	1.364	1.811	2.465	277.4	319.6	388.1	3.707	4.572	5.775	10202	12655	16567
PLR002	2.041	2.62	3.396	205.6	232.4	266.6	5.577	6.561	7.888	7524	9278	11481
PLR003	2.182	2.775	3.471	232.3	257.4	289.3	5.829	6.939	8.171	8696	10294	12288
PLR004	4.379	5.612	5.901	109.7	113.8	113.1	35.968	39.144	42.239	1335	1632	1579
PLR005	8.599	11.703	13.655	138.4	151.8	157.4	32.694	36.143	39.373	3641	4915	5460
PLR006	1.962	2.623	3.441	281.3	317.5	367.9	4.606	5.815	7.257	11982	14323	17447
PLR007	1.013	1.33	1.641	302.4	338.5	392.4	2.83	3.449	4.054	10820	13053	15880
PLR008	2.399	3.452	4.504	293.5	345.8	395	5.417	7.327	9.13	12998	16295	19485
PLR009	1.781	2.669	3.733	266.3	326.4	400.1	4.551	6.137	8.008	10419	14196	18648
PLR010	1.472	1.902	2.306	281.8	331.8	373.2	4.168	5.063	5.864	9949	12465	14681
PLR011	1.723	2.467	3.352	324.6	369.6	421.3	4.085	5.448	6.957	13694	16740	20298
PLR012	0.959	1.322	1.75	261.7	306.3	373.2	3.041	3.779	4.609	8253	10717	14167
PLR013	1.842	2.403	2.979	331.5	371.7	422.6	4.241	5.275	6.264	14399	16933	20096
PLR014	1.794	2.464	3.256	341.5	391.1	439.3	4.472	5.752	7.182	13694	16751	19914
PLR015	2.141	2.83	3.745	290.5	330	400.9	5.733	6.992	8.532	10848	13353	17596
PLR016	2.268	2.823	3.325	211.4	243.5	274.1	5.434	6.258	7.045	8825	10459	12938
PLR017	2.003	2.506	2.994	227.6	262.4	305	6.176	7.058	7.911	7381	9315	11543
PLR018	1.88	2.454	3.217	248	264.8	303.9	5.134	6.33	7.736	9080	10263	12638
PLR019	2.403	3.008	3.54	229.2	260.8	293.4	7.228	8.336	9.214	7621	9411	11272
PLR020	1.085	1.369	1.627	251.8	307.6	367.2	3.9	4.525	5.116	7004	9308	11681
PLR021	2.242	3.16	4.236	296.1	350.5	413.7	5.122	6.738	8.587	12959	16441	20409
PLR022	0.631	0.776	0.963	396.8	457	538.3	2.094	2.442	2.909	11953	14526	17825
PLR023	1.463	1.832	2.18	280	293.6	313.6	4.248	5.064	5.781	9642	10625	11826
PLR024	1.459	1.838	2.252	358.9	415.8	480.1	4.042	4.837	5.644	12953	15798	19154
PLR025	1.152	1.473	1.743	256.3	309.6	362.9	4.025	4.727	5.304	7335	9651	11927
PLR026	1.437	2.003	2.627	275.6	311.8	359	3.568	4.635	5.702	11100	13469	16541
PLR027	2.089	2.789	3.675	261.8	295.9	340.8	5.372	6.612	8.021	10181	12480	15613
PLR028	1.759	2.405	3.178	228	261.5	311.1	4.397	5.556	6.839	9121	11321	14454
PLR030	0.824	1.105	1.419	300.5	332.2	383.9	2.822	3.495	4.198	8779	10503	12973
PLR031	3.561	4.554	5.459	271.6	314.8	368.4	8.205	9.882	11.337	11785	14507	17736
PLR032	1.622	2.107	2.666	256.4	280.9	316.9	4.703	5.712	6.805	8846	10360	12415

PLR033	0.901	1.11	1.323	335.9	387.2	440.4	2.831	3.324	3.81	10687	12926	15291
PLR034	2.476	3.373	4.337	292.1	310.9	336.1	5.667	7.297	8.922	12763	14373	16338
PLR035	2.436	3.01	3.651	290.8	316.9	353.1	6.124	7.222	8.347	11569	13209	15445
PLR036	1.416	1.845	2.439	260	312	385.2	3.796	4.614	5.696	9699	12477	16496
PLR037	1.124	1.631	2.459	309	379.5	495.3	3.223	4.252	5.713	10775	14556	21319
PLR038	3.71	4.744	5.508	171.2	187	195.8	11.521	13.127	14.455	5513	6758	7460
PLR039	2.353	2.951	3.461	227.3	256.4	278.6	6.976	8.063	8.986	7666	9385	10730
PLR040	13.811	15.953	18.081	198.4	211.7	224.3	31.034	33.863	36.829	8831	9972	11012
PLR041	6.369	8.006	9.183	209.6	230.9	239.2	14.52	17.026	19.17	9195	10855	11457
PLR043	13.647	16.1	18.277	168.1	172.8	176	34.949	39.597	43.694	6563	7027	7364
PLR044	10.502	11.923	13.47	152.2	157.1	161.5	31.539	33.749	36.305	5068	5551	5992
PLR045	7.26	9.535	12.051	176.3	204.9	242.7	19.495	21.906	25.043	6564	8917	11680
PLR046	3.834	4.716	5.668	223.5	245.6	270.4	9.295	10.792	12.313	9218	10731	12448
PLR047	3.806	4.61	5.958	160.9	167.4	182.6	12.11	13.676	15.675	5056	5644	6940
PLR048	6.152	7.629	9.296	141.3	151	162	22.493	24.115	25.893	3865	4778	5816
PLR049	1.567	2.147	2.743	172	195.6	224.2	5.471	6.42	7.346	4927	6542	8372
PLR050	4.797	5.869	7.34	144.4	152.2	162.9	17.768	19.342	21.281	3900	4617	5619
PLR051	3.018	3.717	4.573	228.1	240.5	259.9	7.547	8.846	10.213	9124	10105	11640
PLR052	1.401	1.832	2.292	234.2	273	312.5	4.73	5.619	6.561	6935	8901	10915
PLR053	1.626	2.025	2.493	223	245.5	275.4	5.691	6.531	7.484	6373	7612	9173
PLR054	3.109	3.559	4.099	158.4	162.4	166.1	11.259	12.206	13.363	4375	4734	5096
PLR055	1.951	2.579	3.21	225.4	256	292.5	5.614	6.799	7.941	7831	9711	11824
PLR056	2.287	2.743	3.241	219.8	229.2	242.1	7.177	8.121	9.089	7003	7743	8634
PLR057	3.846	4.392	5.078	198.9	205.7	215.7	10.889	11.884	13.062	7024	7602	8384
PLR058	0.949	1.309	1.736	244.7	288.4	333.6	3.215	4.043	5.011	7224	9338	11559
PLR059	1.817	2.247	2.729	241.5	273.2	315.3	5.535	6.346	7.268	7928	9670	11841
PLR060	4.569	5.404	6.636	209.6	228.1	263.9	11.667	12.971	14.799	8209	9502	11834
PLR061	1.805	2.177	2.809	236.9	248.9	277.8	5.284	6.049	7.198	8094	8956	10840
PLR062	2.073	2.618	3.354	277.6	300.3	332.6	6.313	7.419	8.841	9112	10595	12619
PLR063	1.883	2.362	2.929	246.9	262.5	287.6	5.897	6.895	7.996	7885	8992	10533
PLR064	1.949	2.287	2.889	204.7	210.8	232.5	6.164	6.877	7.963	6473	7008	8433
PLR065	3.873	4.247	4.935	193.7	191.7	198.6	11.941	12.912	14.156	6283	6306	6922
PLR066	2.15	2.59	3.18	210.2	221.9	241.4	7.382	8.272	9.384	6122	6947	8179
PLR067	1.396	1.87	2.431	177.3	196.1	221.1	5.833	6.782	7.804	4243	5407	6888
PLR068	1.793	2.47	3.067	218	255.2	286.6	6.112	7.419	8.564	6394	8497	10264
PLR069	1.282	1.649	2.186	203.8	220.7	252.4	5.207	6.03	7.132	5019	6034	7733
PLR070	3.84	4.561	5.557	150.3	154.7	161.8	14.835	16.309	18.035	3889	4327	4986
PLR071	2.001	2.301	2.913	198	199.4	215.8	6.374	7.087	8.228	6215	6475	7641
PLR072	1.192	1.51	1.962	207.3	225.4	250.3	3.708	4.312	5.139	6663	7892	9555
PLR073	2.688	3.204	3.963	273.1	289.6	314.7	7.39	8.41	9.855	9937	11033	12655
PLR074	2.548	3.029	3.725	223.5	235	263.8	7.357	8.275	9.474	7741	8601	10371
PLR075	2.032	2.552	3.112	322.9	368.3	411.7	4.821	5.813	6.807	13609	16169	18821
PLR076	2.546	3.032	3.684	339.7	343.1	355.8	6.556	7.56	8.895	13192	13760	14738
PLR077	2.554	3.024	3.774	406.2	423.7	466.4	5.665	6.555	7.833	18312	19548	22471

PLR078	1.226	1.545	1.884	298.3	332.3	381.1	4.469	5.21	5.984	8184	9853	12002
PLR079	3.382	3.742	4.287	167.8	167.1	165.7	10.362	11.446	13.069	5477	5463	5437
PLR080	4.339	5.011	5.808	190.3	199	207.7	11.529	12.685	14.123	7163	7861	8542
PLR081	1.513	2.113	2.645	224.6	285.9	341.1	4.375	5.39	6.327	7769	11207	14261
PLR082	2.177	2.701	3.321	263.9	298.6	336.6	5.815	6.793	7.909	9880	11871	14132
PLR083	0.952	1.169	1.519	226.9	240.4	272.2	3.012	3.5	4.2	7177	8031	9848
PLR084	1.625	2.024	2.432	335.8	384.4	433.7	4.246	5.046	5.829	12852	15416	18091
PLR085	2.064	2.495	2.987	312.9	330	350	5.19	6.07	7.025	12446	13560	14881
PLR086	2.142	2.595	3.32	265.4	283.2	319.4	5.046	5.865	7.065	11266	12534	15010
PLR087	1.42	1.801	2.302	364.2	401.7	464.1	4.475	5.252	6.275	11561	13778	17028
PLR088	1.701	2.028	2.516	265.2	279.4	312.8	5.798	6.522	7.497	7782	8687	10494
PLR089	2.095	3.849	3.06	90.5	99.4	94.7	47.984	50.68	52.916	395	755	548
PLR090	1.432	1.768	2.087	306.6	339.7	359.8	4.226	4.917	5.632	10389	12214	13330
PLR091	1.541	1.824	2.152	324.4	408.4	486.2	4.428	4.936	5.6	11288	15090	18684
PLR092	1.577	1.894	2.252	335.3	398.9	464.4	4.404	5.062	5.84	12010	14924	17911
PLR093	0.855	1.038	1.217	376.9	439	497.5	2.873	3.305	3.767	11213	13790	16068
PLR094	0.993	1.218	1.427	343.9	410.4	475.4	3.126	3.611	4.107	10927	13846	16522
PLR095	0.583	0.754	0.908	285.5	379.9	470.5	2.277	2.682	3.114	7308	10679	13721
PLR096	1.205	1.672	2.05	220.8	287.2	327.7	3.744	4.545	5.342	7111	10565	12575
PLR097	0.785	1.024	1.272	284.6	373.6	455.8	2.881	3.409	4.033	7756	11220	14371
PLR098	0.858	1.083	1.34	298.5	367.3	442.2	2.953	3.451	4.066	8673	11533	14574
PLR099	2.212	3.338	4.247	181.1	241.5	298.5	6.664	8.023	9.417	6012	10046	13460
PLR100	2.936	3.685	4.311	219.8	262.4	277.8	7.957	9.012	10.147	8112	10729	11801
PLR101	3.24	4.05	4.699	195.7	227.4	243.3	8.352	9.369	10.516	7592	9832	10873
PLR102	1.987	2.472	2.992	254	327	405.5	5.34	6.064	7.018	9448	13332	17287
PLR103	0.754	0.861	1.006	428.3	524.3	636.5	2.989	3.263	3.651	10803	13841	17540
PLR104	1.824	2.178	2.493	288	350.7	398.8	5.712	6.312	6.95	9198	12105	14305
PLR105	1.924	2.179	2.483	307.3	388.2	466.4	5.575	5.993	6.611	10603	14112	17519
PLR106	3.075	3.587	4.128	286.1	358.5	413.9	7.695	8.46	9.423	11436	15201	18130
PLR107	1.068	1.336	1.541	250	317.2	372	4.287	4.802	5.269	6230	8824	10881
PLR108	1.197	1.433	1.706	321.8	368.4	469.7	4.515	5.071	5.713	8530	10408	14027
PLR109	1.767	2.311	2.804	220.2	267.6	301.7	5.864	6.791	7.739	6637	9107	10932
PLR110	1.648	2.226	2.758	211.9	274	332.3	4.905	5.739	6.658	7119	10628	13764
PLR111	0.95	1.295	1.605	212.9	271.4	332.1	3.799	4.475	5.166	5325	7853	10318

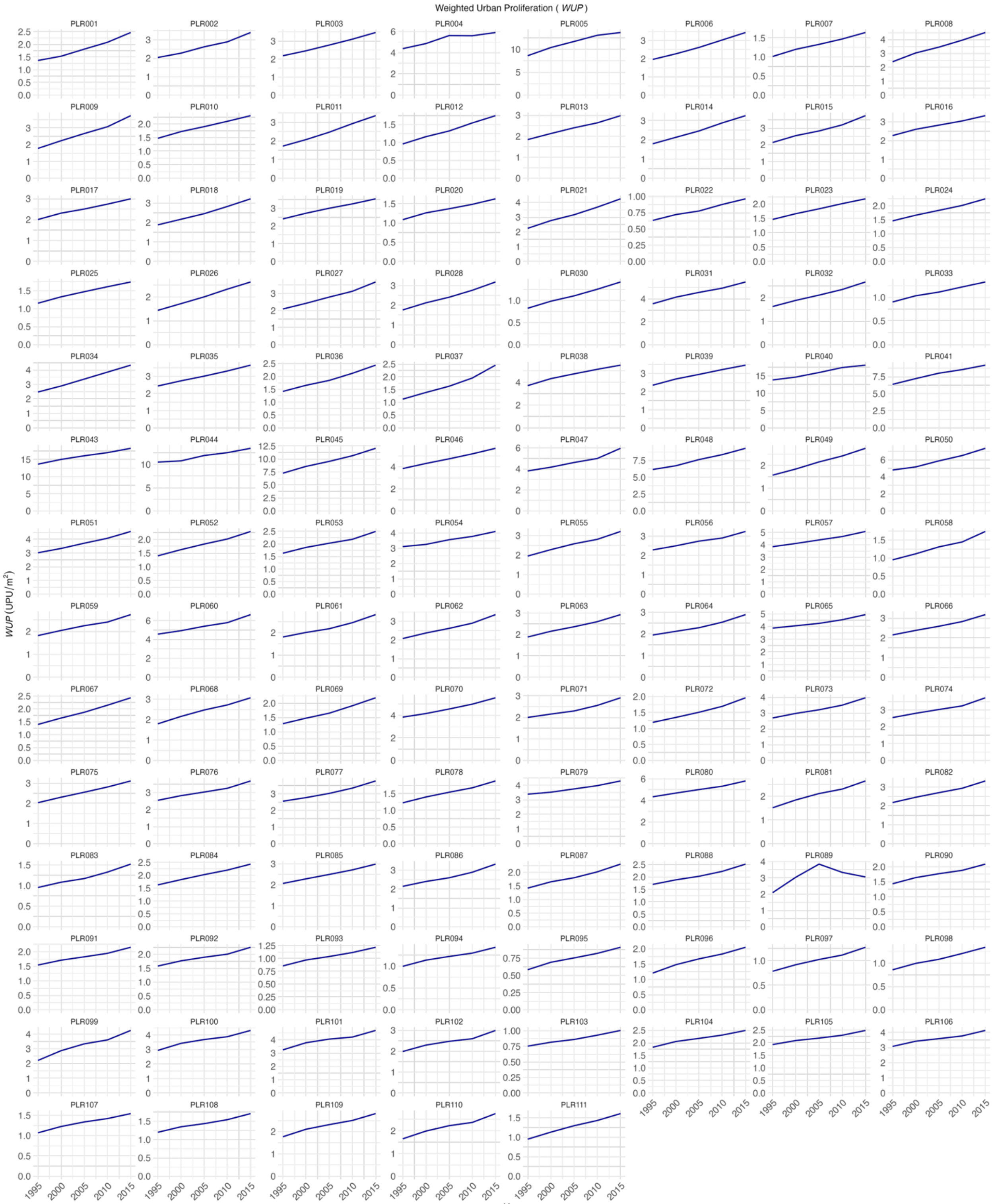

Figure 19 - WUP between 1995 to 2015 across all planning regions in Germany

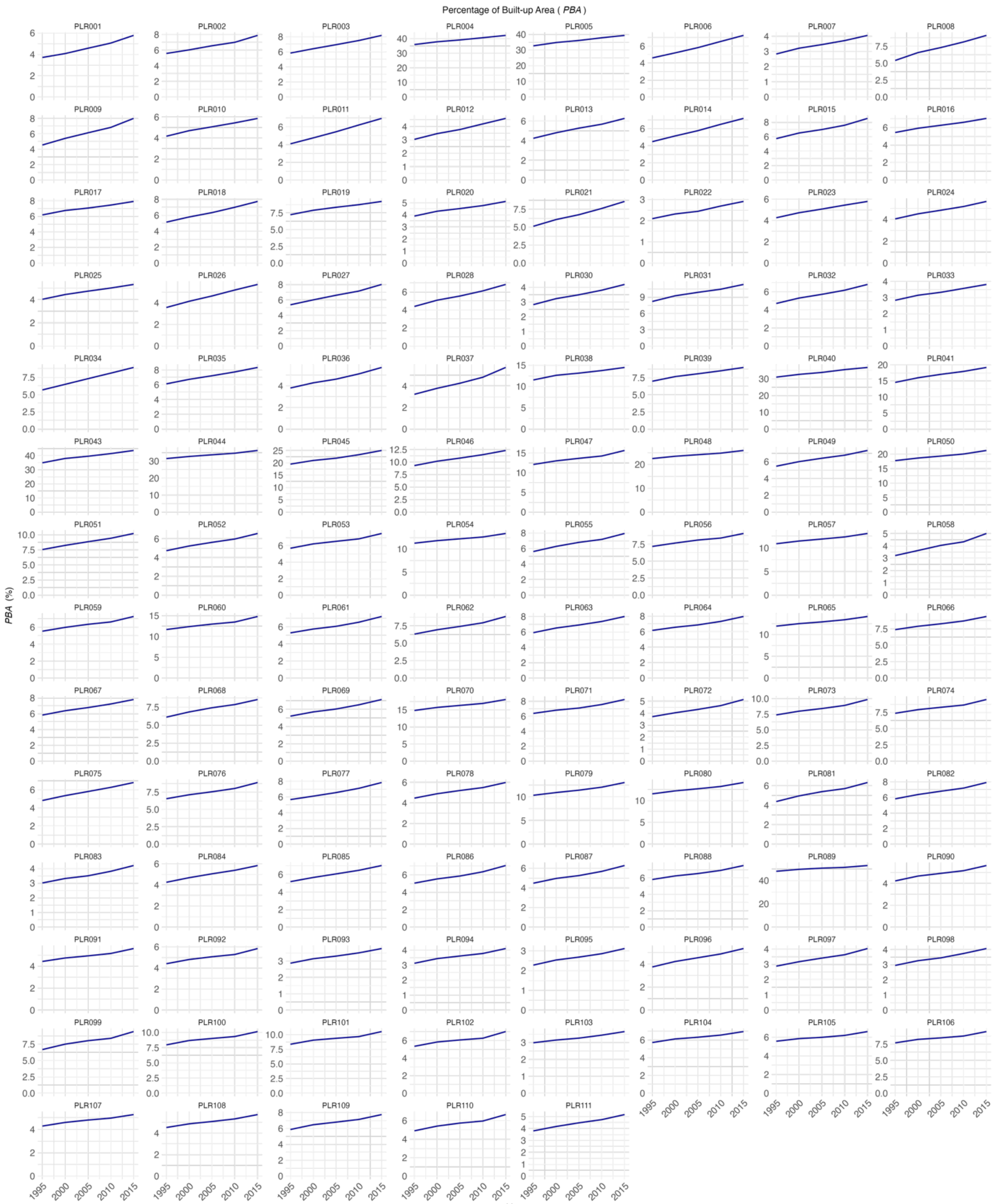

Figure 20 - PBA between 1995 to 2015 across all planning regions in Germany

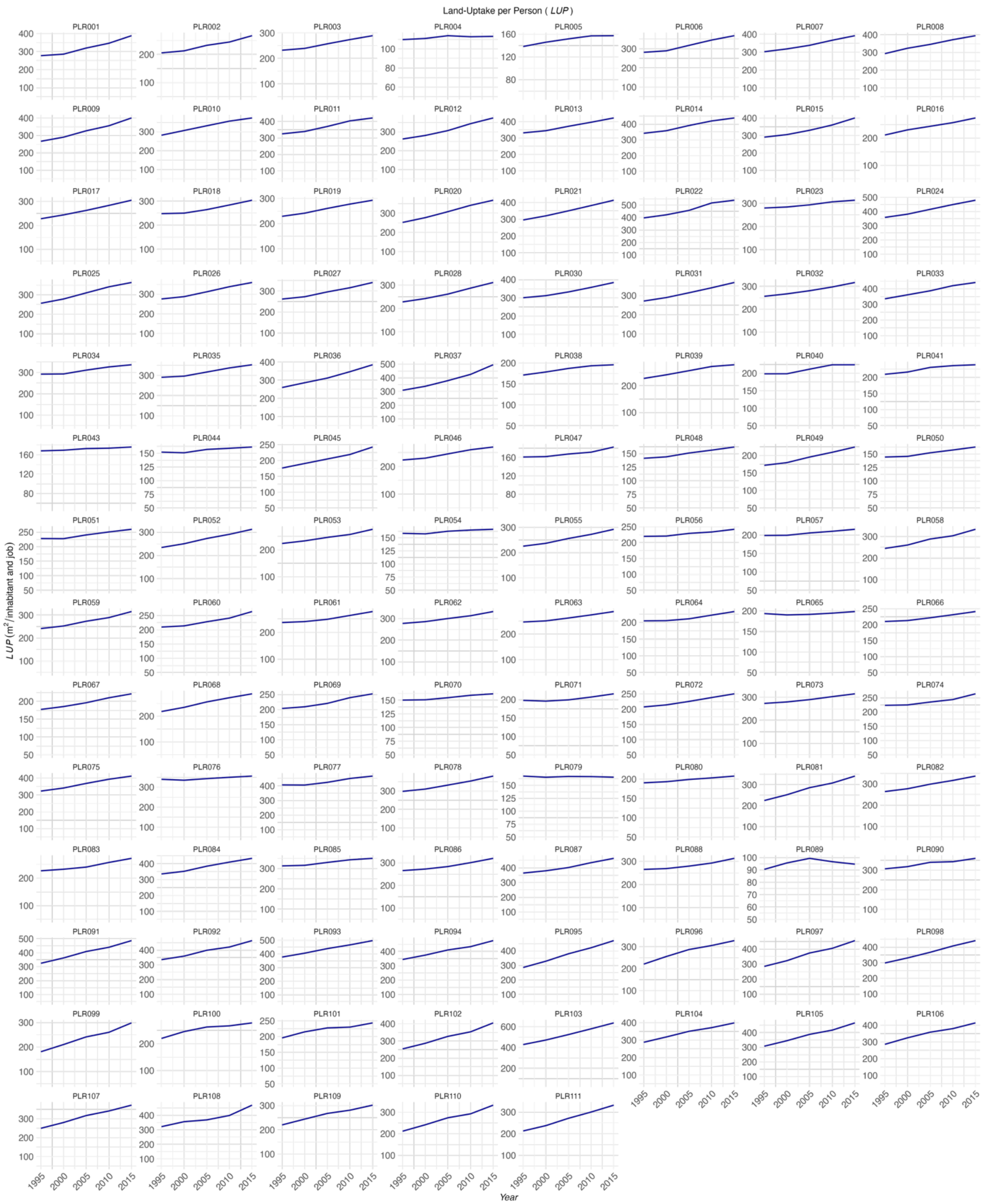

Figure 21 - LUP between 1995 to 2015 across all planning regions in Germany

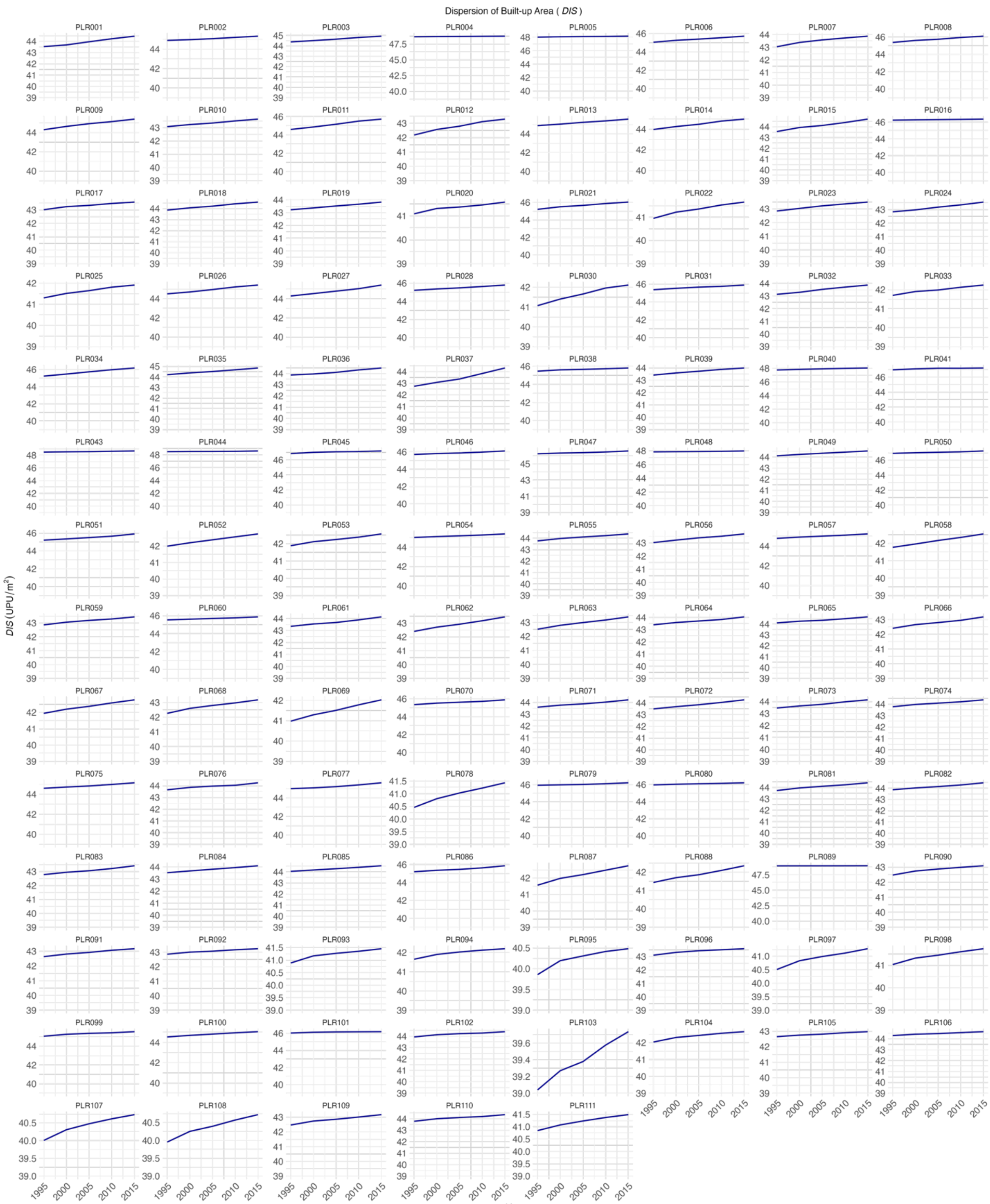

Figure 22 - DIS between 1995 to 2015 across all planning regions in Germany. Please note that the starting point of the Y-axis in all PLRs is set to 39. This standardization allows for easier comparison across regions. However, in regions where the DIS value is closer to 39, the slope of the graph may appear sharper than in others. For a more accurate comparison, please refer to the DIS values in Appendix D.

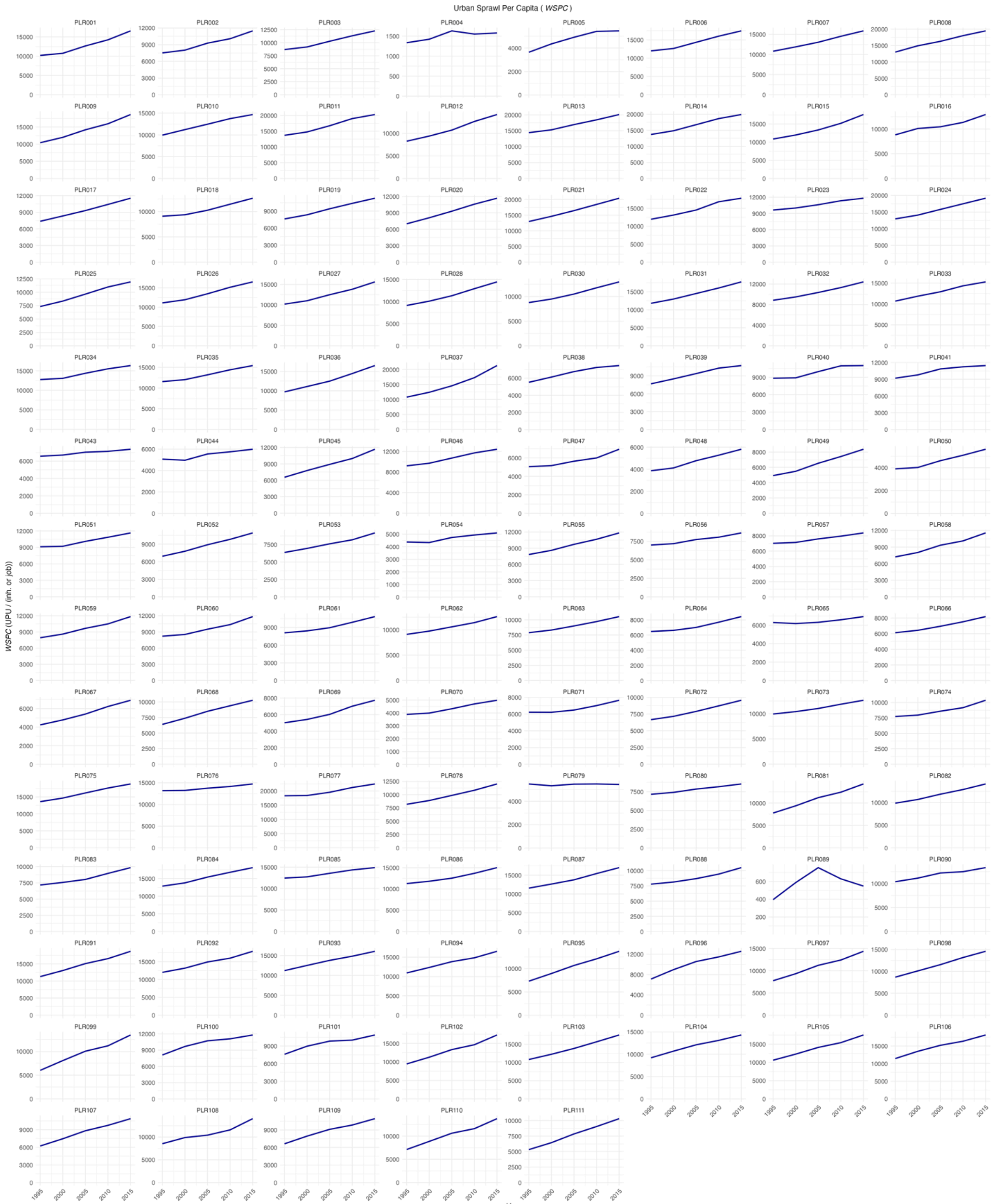

Figure 23 - WSPC between 1995 to 2015 across all planning regions in Germany

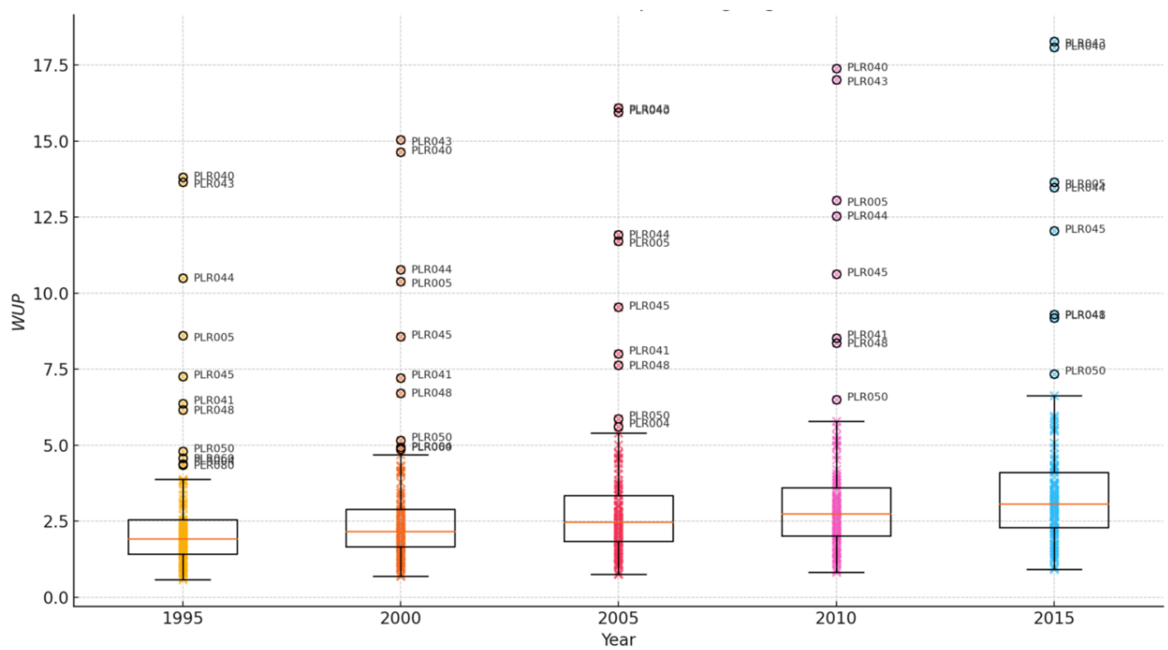

Figure 24 - WUP values across the 111 planning regions of Germany in 2015

4-4- Analysis of references scenarios at the federal level

4-4-1- Scenario 1 - Business as usual

In this scenario, *LUP* continues to increase in line with the current trend observed in each federal state. This increase is based on the observed rise in *LUP* over the 20-year period between 1995 and 2015. Since the *LUP* trend over the past years follows a linear pattern, linear extrapolation is used to predict *LUP* values up to 2050 (Fig. 27). The two states of Hamburg and Berlin do not show a linear behaviour based on the goodness of fit ($R^2 < 0.9$), and the *LUP* pattern differs from the rest of the states, so linear extrapolation could not be applied to these regions. For these regions, scenario 1 is not applied.

The urban sprawl metrics are projected to continue rising over the 35-year period from 2015 to 2050 (Tab. 10). *WUP* is projected to increase by an average of 1.83 UPU/m² across the federal states, representing a 39.83% growth. All states exhibit an upward trend, with Bremen showing the most pronounced rise, from 13.6 to 22.7 UPU/m², an absolute gain of 9.13 UPU/m². In contrast, Sachsen-Anhalt records the smallest increase, with only a 0.32 UPU/m² rise over the period (Fig. 25).

PBA increases in all federal states as well, with an average gain of 2.85 percentage points. Bremen again experienced the highest increase, growing from 39.37 to 50.4% (+11.03 percentage points). In contrast, Sachsen-Anhalt shows the smallest growth, with an absolute increase of only 0.67% (Fig. 26).

DIS displays a slight but steady increase in all states, averaging +0.29 UPU/m² or +0.65%. Schleswig-Holstein experienced 0.41 UPU/m² increase, whereas Sachsen-Anhalt shows the lowest change, at +0.12 UPU/m² (Fig. 28 and Tab. D-1 in appendix D).

WSPC demonstrates significant growth across all states, with an average increase of 5,896 UPU/ (inh. or job), corresponding to +51.54%. The highest projected growth is in Mecklenburg-Vorpommern, where *WSPC* rises by 9,879 UPU/ (inh. or job) (Fig. 29).

Figure 25 – Projected changes in WUP between 2015 – 2050 in Germany's federal states in scenario 1

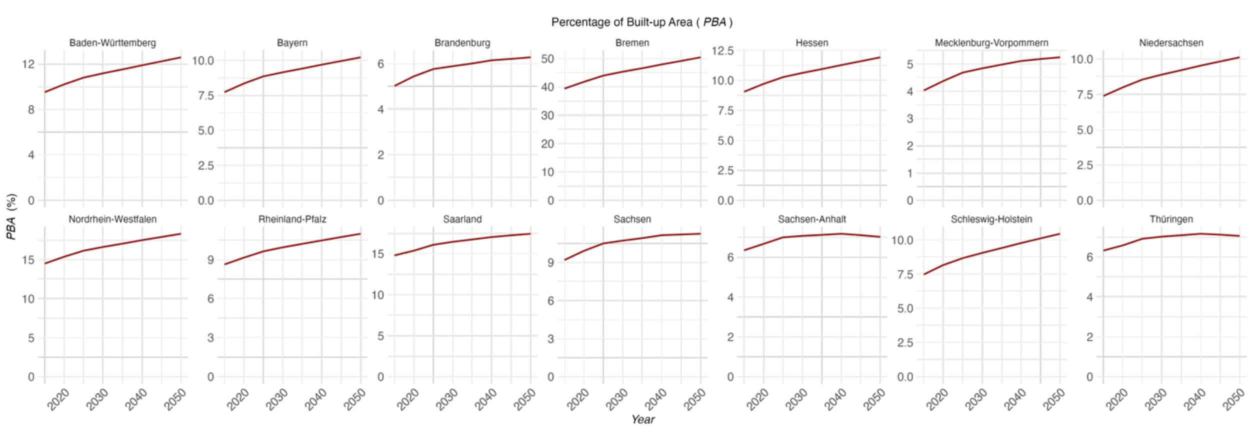

Figure 26 - Projected changes in PBA between 2015 – 2050 in Germany's federal states in scenario 1

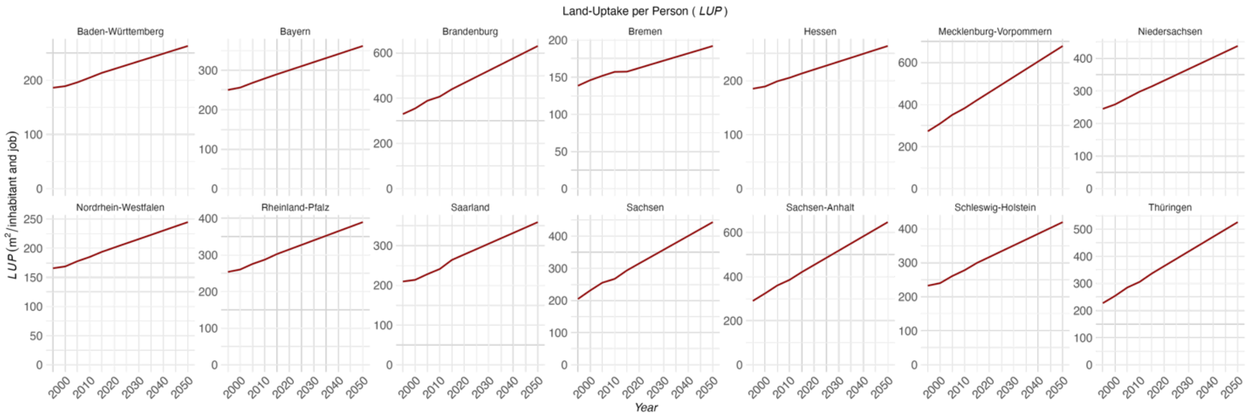

Figure 27 - Projected changes in LUP between 1995 – 2050 in Germany's federal states in scenario 1

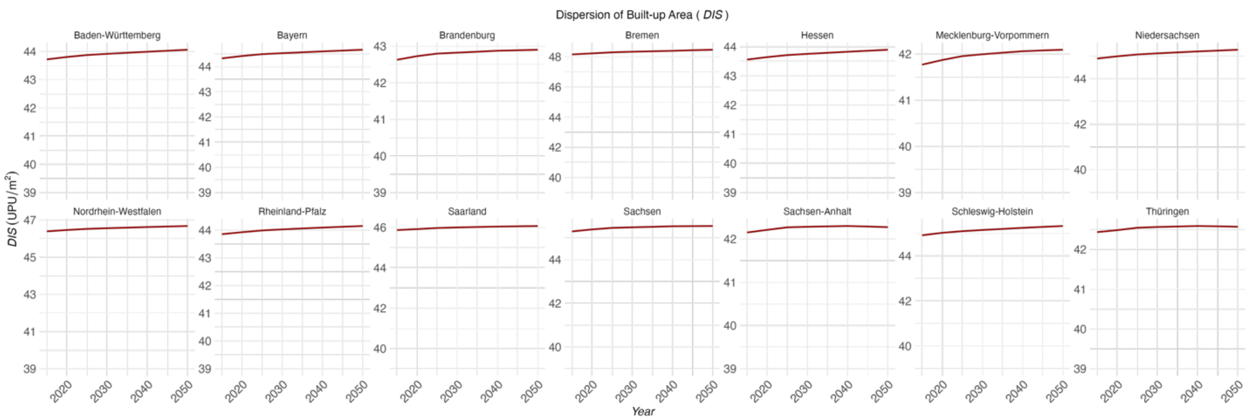

Figure 28 – Projected changes in DIS between 2015 – 2050 in Germany's federal states in scenario 1

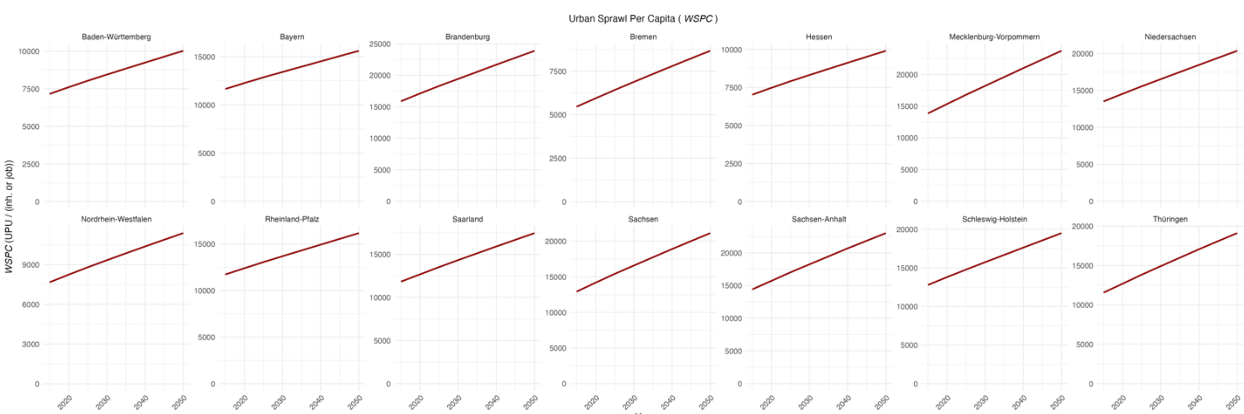

Figure 29 - Projected changes in WSPC between 2015 – 2050 in Germany's federal states in scenario 1

Table 10 - Urban sprawl metrics for scenario 1 in federal states

	WUP (UPU/m²)			*LUP* (m²/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
Federal States	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**
Baden-Württemberg	3.193	3.519	4.797	213.4	220.4	262.8	9.518	10.204	12.583	7158	7602	10021
Bayern	3.103	3.409	4.41	289.8	300	361.4	7.724	8.344	10.216	11642	12258	15603
Brandenburg	1.811	1.993	2.378	439.6	466.8	630.2	5.015	5.439	6.273	15876	17109	23888
Bremen	13.65	15.28	22.78	157.4	162.3	191.9	39.37	41.75	50.4	5457	5940	8670
Hessen	2.984	3.292	4.477	213.1	220.4	263.9	9.047	9.702	11.918	7029	7477	9914
Mecklenburg-Vorpommern	1.327	1.467	1.836	420.5	457.3	678.3	4.029	4.376	5.247	13849	15325	23728
Niedersachsen	3.178	3.508	4.708	314	331.7	437.9	7.382	7.997	10.123	13516	14548	20369
Nordrhein-Westfalen	5.74	6.307	8.521	193.8	201.1	244.7	14.494	15.375	18.315	7676	8249	11386
Rheinland-Pfalz	3.344	3.601	4.557	302.3	314.8	389.4	8.624	9.145	10.98	11724	12393	16164
Saarland	6.637	7.025	8.484	263.9	277.5	358.9	14.799	15.376	17.437	11834	12677	17460
Sachsen	4.044	4.462	5.365	293.5	315	443.5	9.193	9.914	11.261	12913	14176	21128
Sachsen-Anhalt	2.173	2.313	2.497	420.5	452.8	646.7	6.345	6.668	7.019	14402	15703	23009
Schleswig-Holstein	3.191	3.561	4.862	299.1	316.2	419	7.471	8.162	10.449	12775	13796	19496
Thüringen	2.168	2.294	2.56	336.7	363.8	526	6.316	6.577	7.049	11555	12688	19110

4-4-2- Scenario 2 – Constant *LUP*

In this scenario, where *LUP* in 2050 remains equal to its 2015 level (Fig. 32), *WUP* behaves differently across regions. In most federal states, it increases until around 2025, followed by either a decline or further increase (Table 11). In general, regions with projected population growth—namely Hamburg, Bremen, Nordrhein-Westfalen, Hessen, Baden-Württemberg, Bayern, and Berlin—exhibit an average increase of 0.46 UPU/m² (+9.77%) in *WUP* by 2050. In contrast, the remaining nine states, which will face population decline, experience an average decrease of 0.42 UPU/m² (-15.21%) in *WUP* value (Fig. 30).

States in which *WUP* increased also show corresponding increases in *PBA*, *DIS*, and *WSPC*. Conversely, in states where *WUP* decreased, these components decline as well. *PBA* in the seven growing states increases on average by 3.13 percentage points, with Berlin showing the highest absolute change by 11.1% increase between 2015 and 2050. In contrast, in the nine shrinking states, there is an average *PBA* decrease of approximately 1 percentage point, with Saarland experiencing the largest drop from 14.799% to 12.822% (Fig. 31).

DIS in the growing regions rises by an average of 0.10 UPU/m², while in the shrinking regions, it decreases by an average of 0.19 UPU/m² (Fig. 33 and Tab. D-1 in appendix D). *WSPC* shows minimal variation: on average, it increases slightly by 33.92 UPU/ (inh. or job) (+0.71%) in the growing states, while declining by 244.39 UPU/ (inh. or job) (−1.84%) in the shrinking ones (Fig. 34).

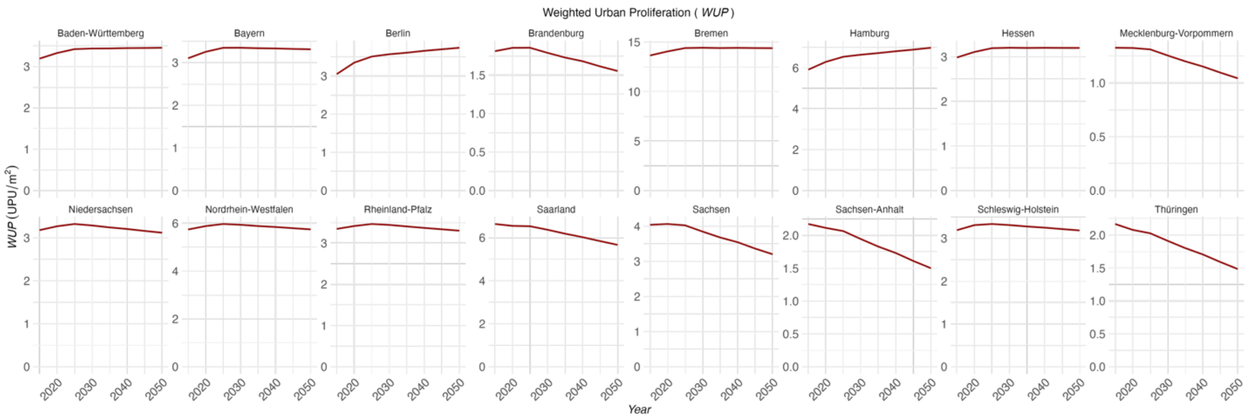

Figure 30 - Projected changes in WUP between 2015 – 2050 in Germany's federal states in scenario 2

Figure 31 - Projected changes in PBA between 2015 – 2050 in Germany's federal states in scenario 2

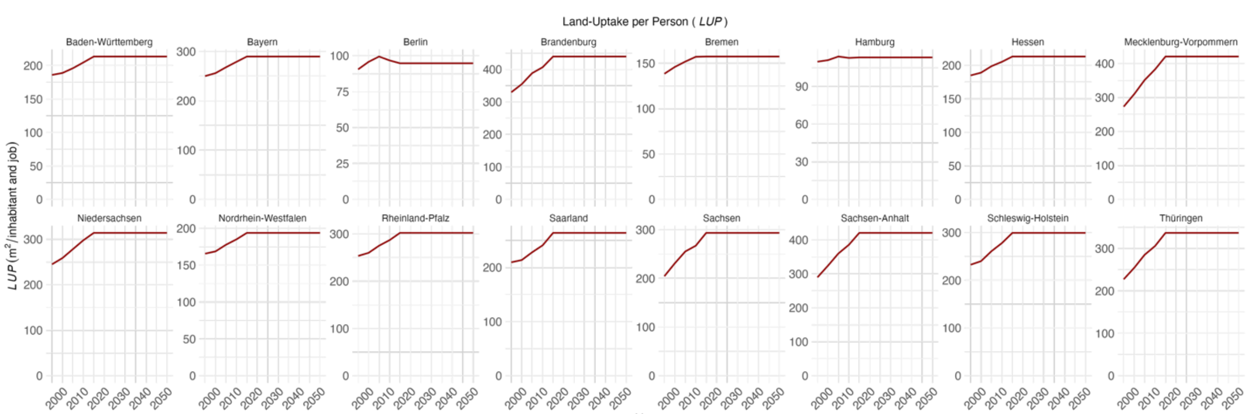

Figure 32 -Projected changes in LUP between 1995 – 2050 in Germany's federal states in scenario 2

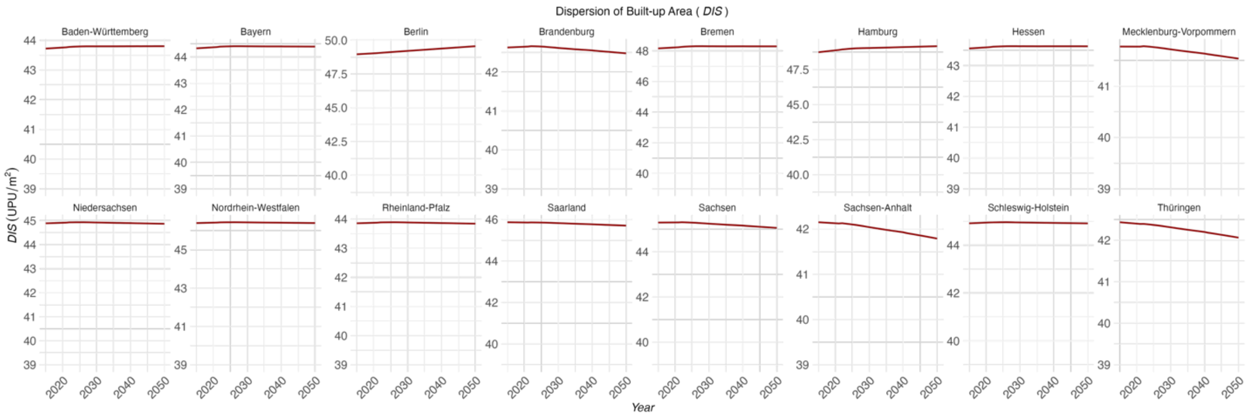

Figure 33 - Projected changes in DIS between 2015 – 2050 in Germany's federal states in scenario 2

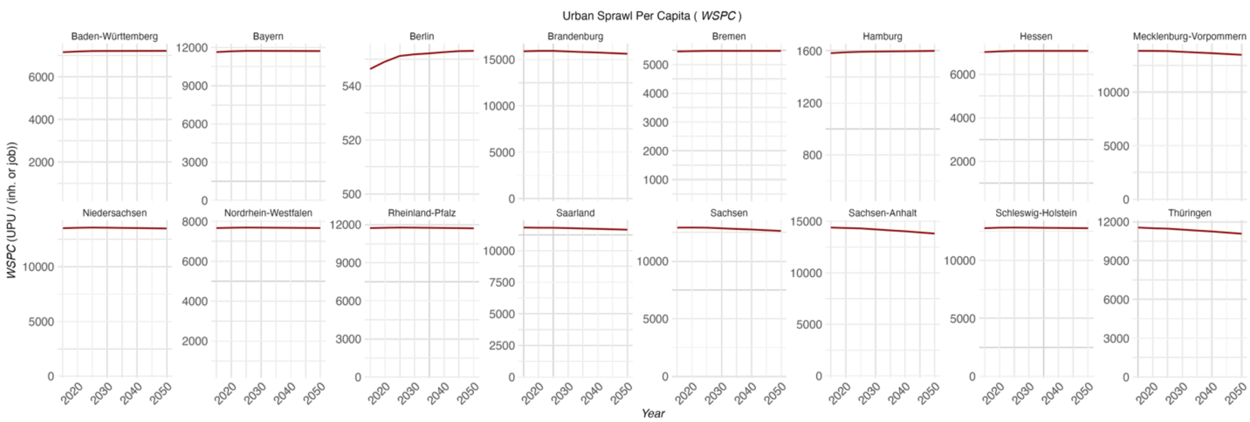

Figure 34 - Projected changes in WSPC between 2015 – 2050 in Germany's federal states in scenario 2

Table 11 - Urban sprawl metrics for scenario 2 in federal states

	WUP (UPU/m^2)			*LUP* (m^2/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
Federal States	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**
Baden-Württemberg	3.193	3.328	3.456	213.4	213.4	213.4	9.518	9.877	10.214	7158	7190	7219
Bayern	3.103	3.254	3.313	289.8	289.8	289.8	7.724	8.059	8.191	11642	11699	11720
Berlin	3.05	3.35	3.74	94.7	94.7	94.7	52.893	57.66	64.009	546	549	553
Brandenburg	1.811	1.854	1.553	439.6	439.6	439.6	5.015	5.122	4.376	15876	15917	15608
Bremen	13.65	14.06	14.39	157.4	157.4	157.4	39.368	40.48	41.352	5457	5469	5478
Hamburg	5.91	6.29	6.98	113.1	113.1	113.1	42.257	44.791	49.325	1583	1589	1600
Hessen	2.984	3.108	3.198	213.1	213.1	213.1	9.047	9.383	9.623	7029	7060	7081
Mecklenburg-Vorpommern	1.327	1.325	1.043	420.5	420.5	420.5	4.029	4.024	3.253	13849	13846	13481
Niedersachsen	3.178	3.268	3.118	314	314	314	7.382	7.57	7.257	13516	13554	13491
Nordrhein-Westfalen	5.74	5.881	5.745	193.8	193.8	193.8	14.494	14.819	14.505	7676	7692	7677
Rheinland-Pfalz	3.344	3.414	3.301	302.3	302.3	302.3	8.624	8.784	8.524	11724	11749	11708
Saarland	6.637	6.55	5.667	263.9	263.9	263.9	14.799	14.624	12.822	11834	11820	11663
Sachsen	4.044	4.067	3.205	293.5	293.5	293.5	9.193	9.239	7.453	12913	12919	12624

Sachsen-Anhalt	2.173	2.114	1.5	420.5	420.5	420.5	6.345	6.193	4.564	14402	14358	13818
Schleswig-Holstein	3.191	3.309	3.185	299.1	299.1	299.1	7.471	7.72	7.459	12775	12821	12773
Thüringen	2.168	2.079	1.484	336.7	336.7	336.7	6.316	6.088	4.512	11555	11502	11078

4-4-3- Scenario 3 - *WUP* mirrors population and employment trends

Similar to scenario 2, the urban sprawl metrics behave differently depending on whether a state's population increases or decreases by 2050. The nine states of Brandenburg, Mecklenburg-Vorpommern, Niedersachsen, Rheinland-Pfalz, Saarland, Sachsen, Sachsen-Anhalt, Schleswig-Holstein, and Thüringen are projected to experience a decline in the number of inhabitants and jobs by 2050. In these states, *WUP*, *PBA*, and *DIS* all show a declining trend over time (Figs. 35, 36 & 38). The average *WUP* decrease is 0.38 UPU/m² (−13.77%), with the most severe decline observed in Saarland (−0.89 UPU/m²). *PBA* decreases by an average of 0.91 percentage points and *DIS* declines by 0.17 UPU/m² on average (Tab. D-1 in appendix D). In some states, such as Brandenburg and Niedersachsen, we observe an initial increase followed by a decrease. This pattern is due to the population growth between 2015 and 2021.

In contrast, the remaining seven states in which population increases between 2015 and 2050, show upward trends in these metrics. *WUP* rises by an average of +0.42 UPU/m² (+8.94%), with Hamburg showing the highest increase (+0.99 UPU/m²). *PBA* increases by an average of 3.02 percentage points, with Berlin experiencing the most substantial rise from 52.893% in 2015 to 63.746% in 2050 (+10.85 percentage points). *DIS* in these states also increases by an average of +0.20 UPU/m² (+0.41%) (Fig. 38 and Appendix D).

LUP did not change much in both groups (Tab. 12 and Fig. 37). In growing states, it slightly decreased by −0.69 m²/ (inh. or job) (−0.38%) on average, while in the shrinking states, it slightly increases by +5.55 m²/ (inh. or job) (+1.49%). *WSPC* remains constant overall, as the relative change in the value of *WUP* and inhabitants and jobs are similar (Fig. 39).

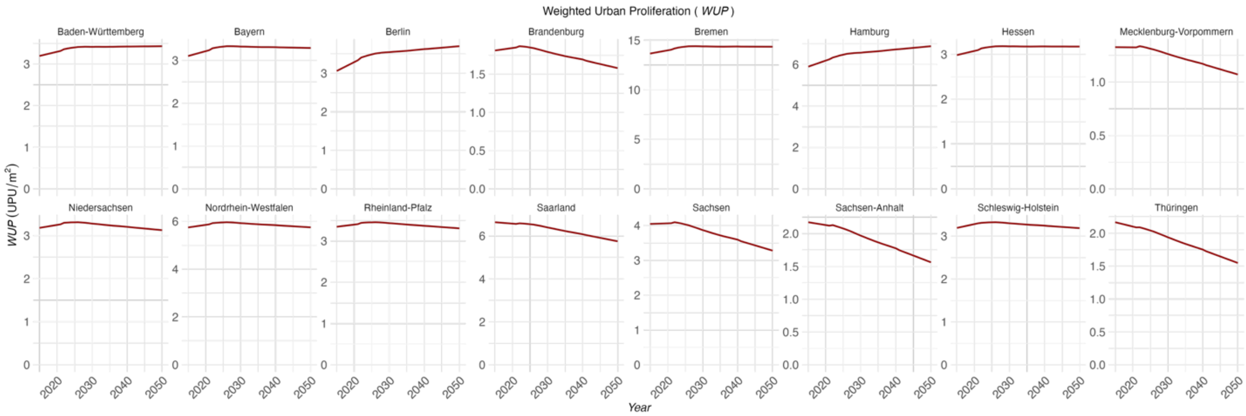

Figure 35 - Projected changes in WUP between 2015 – 2050 in Germany's federal states in scenario 3

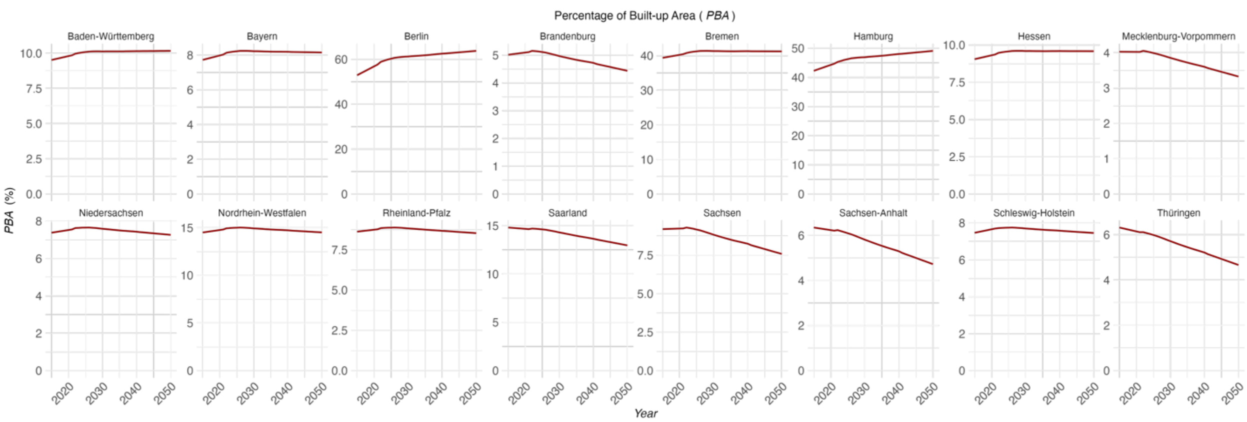

Figure 36 - Projected changes in PBA between 2015 – 2050 in Germany's federal states in scenario 3

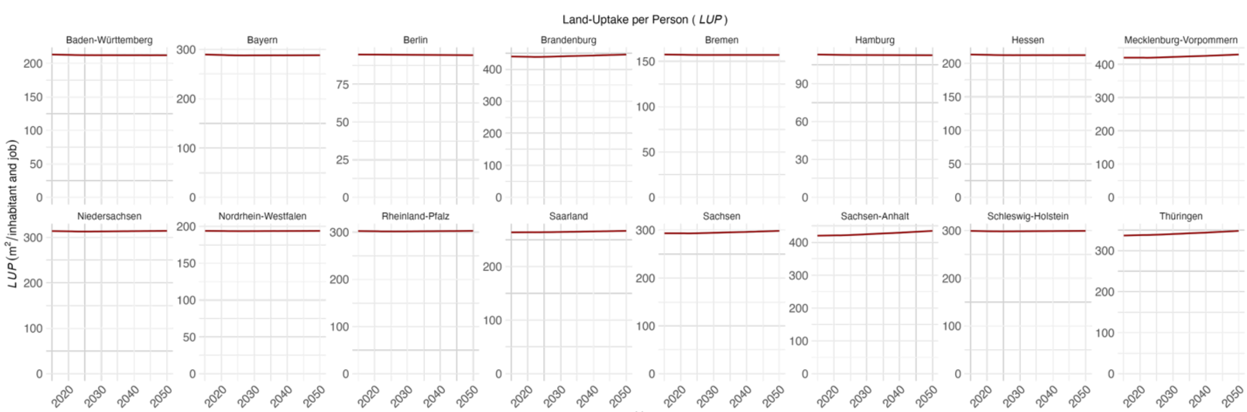

Figure 37 - Projected changes in LUP between 2015 – 2050 in Germany's federal states in scenario 3

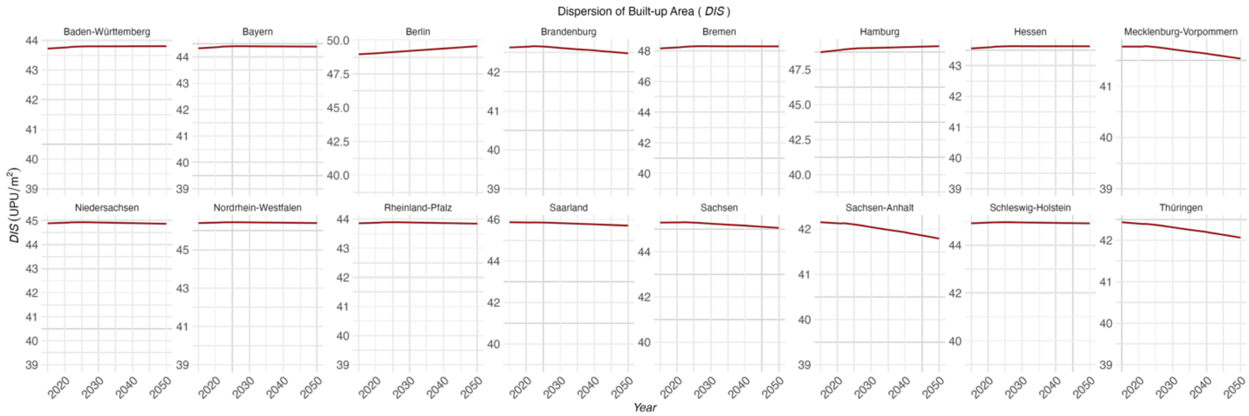

Figure 38 - Projected changes in DIS between 2015 – 2050 in Germany's federal states in scenario 3

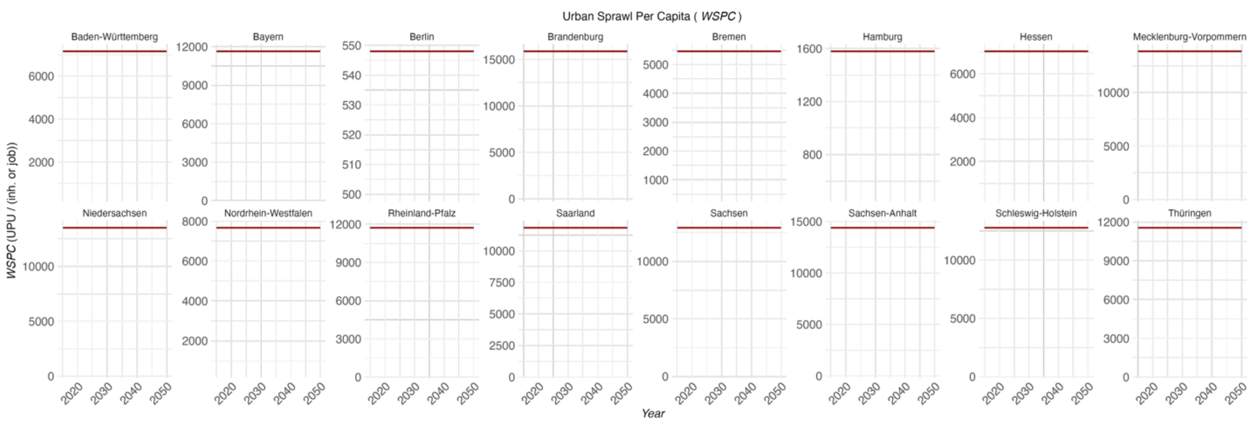

Figure 39 – Projected changes in WSPC between 2015 – 2050 in Germany's federal states in scenario 3

Table 12 - Urban sprawl metrics for scenario 3 in Germany's federal states

	WUP (UPU/m^2)			*LUP* (m^2/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
Federal States	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**
Baden-Württemberg	3.193	3.313	3.427	213.37	212.79	212.31	9.518	9.851	10.164	7158	7158	7158
Bayern	3.103	3.238	3.291	289.76	288.68	288.35	7.724	8.029	8.151	11642	11642	11642
Berlin	3.06	3.336	3.703	94.74	94.68	94.31	52.893	57.645	63.746	548	548	548
Brandenburg	1.811	1.85	1.58	439.61	438.62	445.8	5.015	5.11	4.437	15876	15876	15876
Bremen	13.655	14.041	14.343	157.42	157.16	156.96	39.368	40.418	41.235	5460	5460	5460
Hamburg	5.901	6.254	6.888	113.1	112.86	112.55	42.257	44.696	49.085	1579	1579	1579
Hessen	2.984	3.095	3.174	213.1	212.58	212.2	9.047	9.36	9.582	7029	7029	7029
Mecklenburg-Vorpommern	1.327	1.325	1.071	420.47	420.51	429.92	4.029	4.024	3.326	13849	13849	13849
Niedersachsen	3.178	3.259	3.124	313.95	313.32	314.36	7.382	7.555	7.266	13516	13516	13516
Nordrhein-Westfalen	5.74	5.868	5.744	193.83	193.64	193.8	14.494	14.804	14.504	7676	7676	7676
Rheinland-Pfalz	3.344	3.406	3.305	302.32	301.85	302.59	8.624	8.77	8.531	11724	11724	11724
Saarland	6.636	6.558	5.75	263.9	264.08	266.61	14.799	14.634	12.954	11834	11834	11834
Sachsen	4.044	4.064	3.279	293.53	293.46	298.52	9.193	9.237	7.58	12913	12913	12913

Sachsen-Anhalt	2.173	2.121	1.563	420.5	421.49	435.04	6.345	6.207	4.722	14402	14402	14402
Schleswig-Holstein	3.191	3.297	3.186	299.09	298.26	299.13	7.471	7.699	7.46	12775	12775	12775
Thüringen	2.167	2.089	1.548	336.72	337.95	348.04	6.316	6.11	4.663	11555	11555	11555

4-4-4- Scenario 4 – Constant urban sprawl

By keeping the *WUP* constant over the years (Fig. 40), in regions with increasing population, both *PBA* and *DIS* rose (Figs. 41 & 43). *PBA* increased by an average of 2.44 percentage points, with the highest increases observed in Berlin and Hamburg (+9.78 percentage points and +5.54 percentage points, respectively). *DIS* also increased slightly by an average of 0.066 UPU/m² (+0.14%), again with Berlin showing the highest rise (+0.20 UPU/m²) (Tab. D-1 in appendix D).

On the other hand, *LUP* and *WSPC* decreased in these regions (Figs. 42 & 44). *LUP* dropped slightly by 5.69 m²/ (inh. or job) (−2.93%), and *WSPC* experienced an average decrease of 308.8 UPU/ (inh. or job) (−7.87%), with the most substantial reduction seen in Bayern (−663.5 UPU/ (inh. or job)).

In regions with decreasing population, *PBA* decreased by an average of 0.12 percentage point, with the largest drop in Saarland (−0.41 percentage point). *DIS* declined slightly by an average of 0.018 UPU/m² (−0.04%). However, in this context, both *LUP* and *WSPC* increased. *LUP* rose by an average of 58.45 m²/ (inh. or job) (+15.87%), and *WSPC* by an average of 2,344 UPU/ (inh. or job) (+17.70%) (Tab. 13).

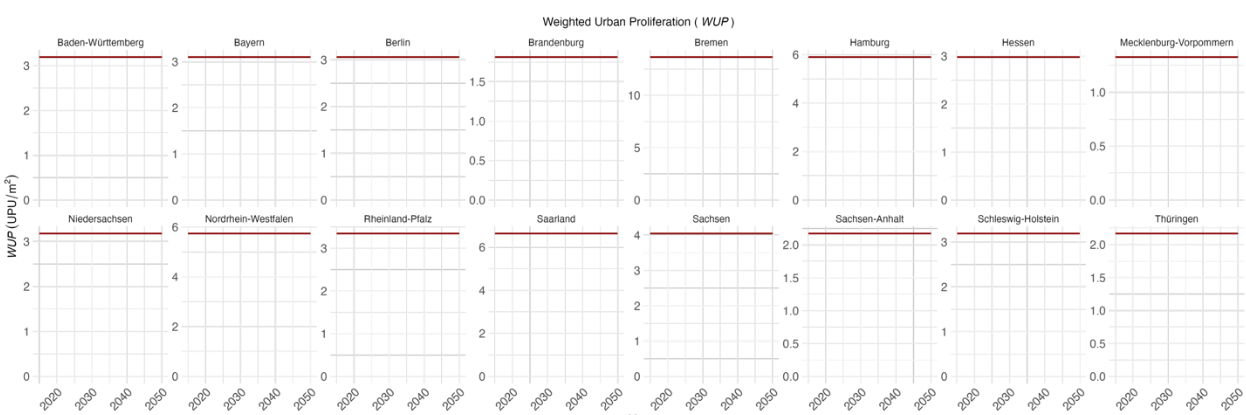

Figure 40 - Projected changes in WUP between 2015 – 2050 in Germany's federal states in scenario 4

Figure 41 - Projected changes in PBA between 2015 – 2050 in Germany's federal states in scenario 4

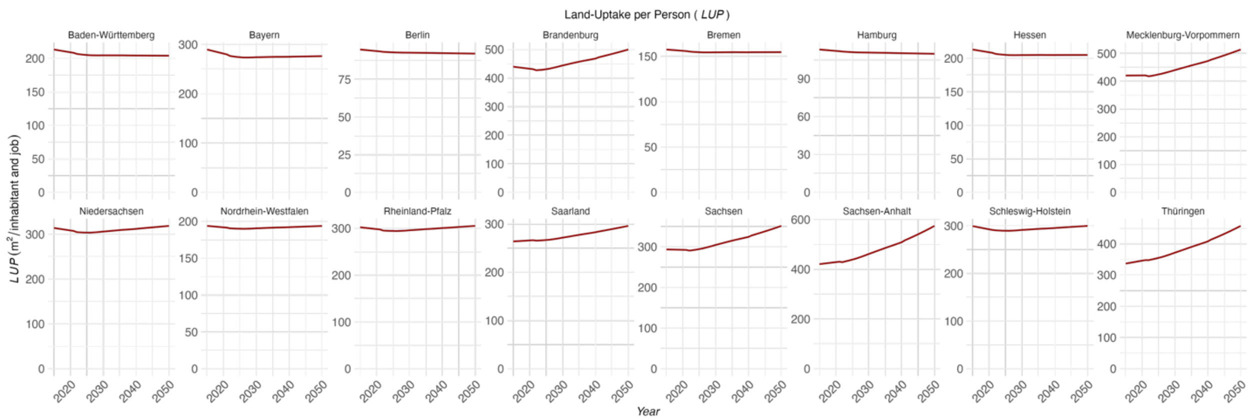

Figure 42 - Projected changes in LUP between 2015 – 2050 in Germany's federal states in scenario 4

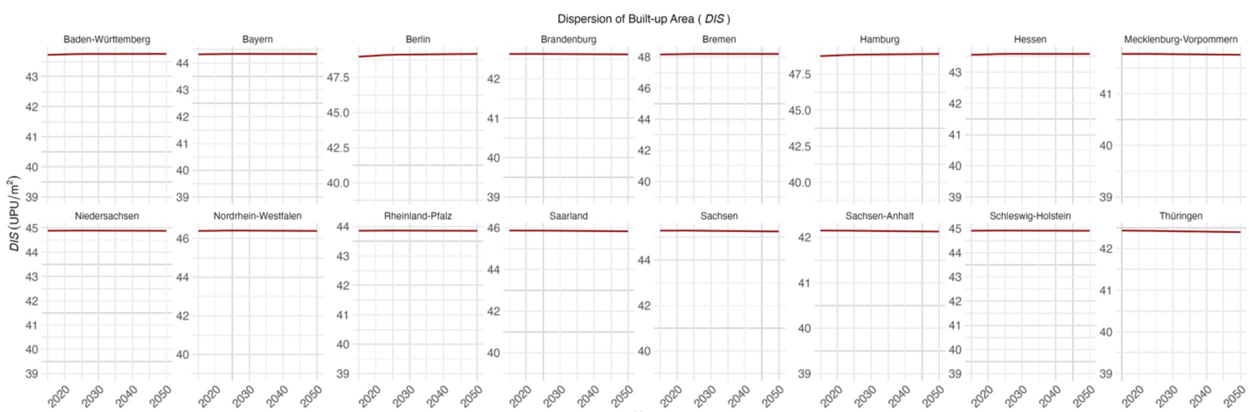

Figure 43 - Projected changes in DIS between 2015 – 2050 in Germany's federal states in scenario 4

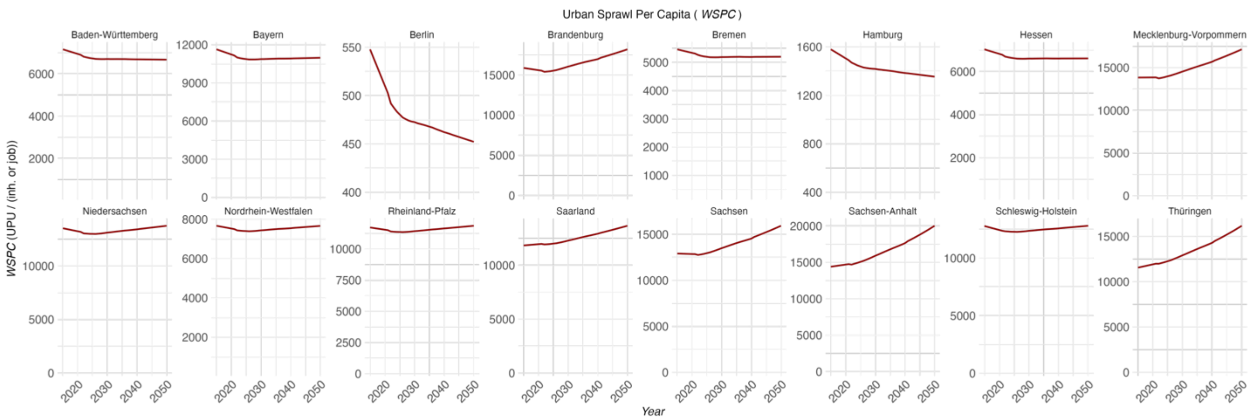

Figure 44 - Projected changes in WSPC between 2015 – 2050 in Germany's federal states in scenario 4

Table 13 - Urban sprawl metrics for scenario 4 in Germany's federal states

	WUP (UPU/m²)			*LUP* (m²/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
Federal States	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**
Baden-Württemberg	3.193	3.193	3.193	213.37	208.41	204.14	9.518	9.647	9.772	7158	6897	6670
Bayern	3.103	3.103	3.103	289.76	279.91	276.29	7.724	7.785	7.81	11642	11157	10978
Berlin	3.06	3.06	3.06	94.74	93.51	92.04	52.893	57.423	62.671	548	503	452
Brandenburg	1.811	1.811	1.811	439.61	431.07	499.75	5.015	5.022	4.974	15876	15545	18195
Bremen	13.655	13.655	13.655	157.42	155.75	154.53	39.373	40.055	40.577	5460	5310	5198
Hamburg	5.901	5.901	5.901	113.05	111.75	109.68	42.257	44.254	47.801	1579	1490	1354
Hessen	2.984	2.984	2.984	213.1	208.23	205	9.047	9.168	9.257	7029	6777	6608
Mecklenburg-Vorpommern	1.327	1.327	1.327	420.47	421.01	514.06	4.029	4.029	3.977	13849	13866	17153
Niedersachsen	3.178	3.178	3.178	313.95	307.31	318.57	7.382	7.41	7.364	13516	13180	13749
Nordrhein-Westfalen	5.74	5.74	5.74	193.83	191.45	193.74	14.494	14.637	14.499	7676	7508	7670
Rheinland-Pfalz	3.344	3.344	3.344	302.32	297.72	305.31	8.624	8.65	8.608	11724	11511	11862
Saarland	6.637	6.637	6.637	263.9	266.36	296.09	14.799	14.761	14.386	11834	11976	13659
Sachsen	4.044	4.044	4.044	293.53	292.32	351.39	9.193	9.201	8.922	12913	12848	15928
Sachsen-Anhalt	2.173	2.173	2.173	420.5	430.12	574.1	6.345	6.334	6.231	14402	14757	20023
Schleswig-Holstein	3.191	3.191	3.191	299.09	291.08	299.52	7.471	7.513	7.469	12775	12363	12797
Thüringen	2.168	2.168	2.168	336.72	347.84	457.33	6.316	6.289	6.128	11555	11989	16177

4-4-5- Scenario 5A - Densification in states with growing population

When keeping the built-up area constant, *PBA* remained unchanged (Fig. 46). Since *DIS* is estimated as a function of *PBA*, it also remained constant (Fig. 48 & Tab. D-1 in appendix D). All other metrics decreased considerably across all federal states (Tab. 14). *WUP* declined by an average of 0.98 UPU/m² (−20.75%) with Hamburg and Berlin showing the largest reductions

(−3.16 and −2.21 UPU/m² decrease respectively) (Fig. 45). *LUP* decreased on average by 12.01 m²/ (inh. or job) (−7.86%) (Fig. 47). *WSPC* experienced a sharp drop, decreasing by an average of 633.59 UPU/ (inh. or job) (−25.57%). The most significant decrease in *WSPC* was observed in Hamburg, where it fell from 1,583 to 630 UPU/ (inh. or job) over the 35-year period (Fig. 49).

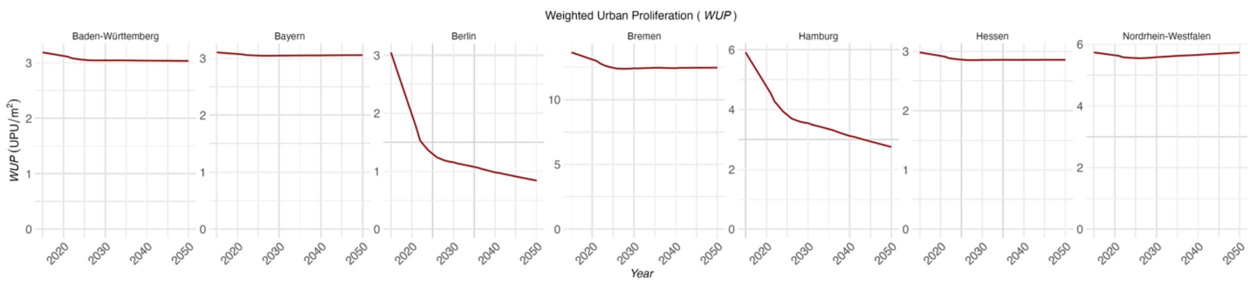

Figure 45 - Projected changes in WUP between 2015 – 2050 in Germany's federal states in scenario 5A

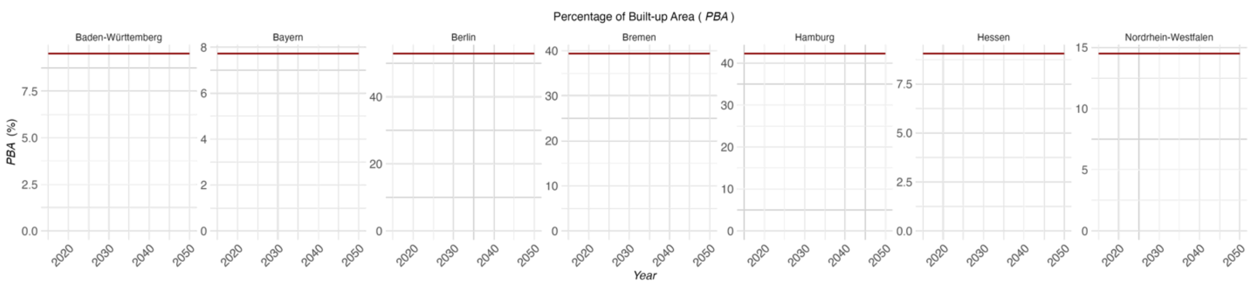

Figure 46 - Projected changes in PBA between 2015 – 2050 in Germany's federal states in scenario 5A

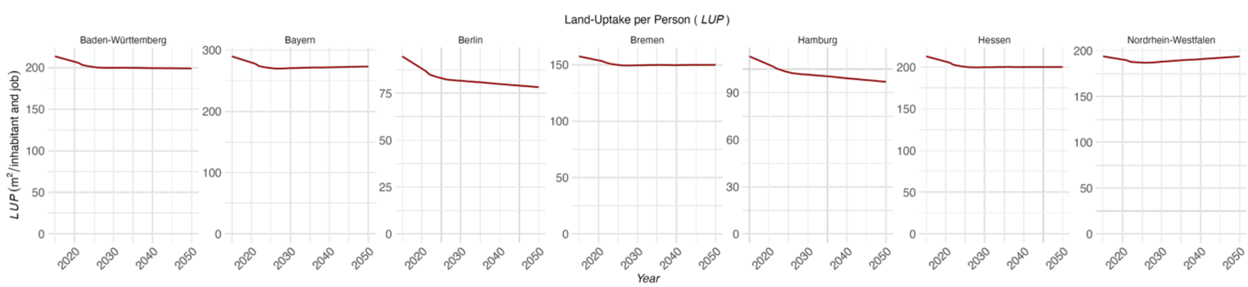

Figure 47 - Projected changes in LUP between 2015 – 2050 in Germany's federal states in scenario 5A

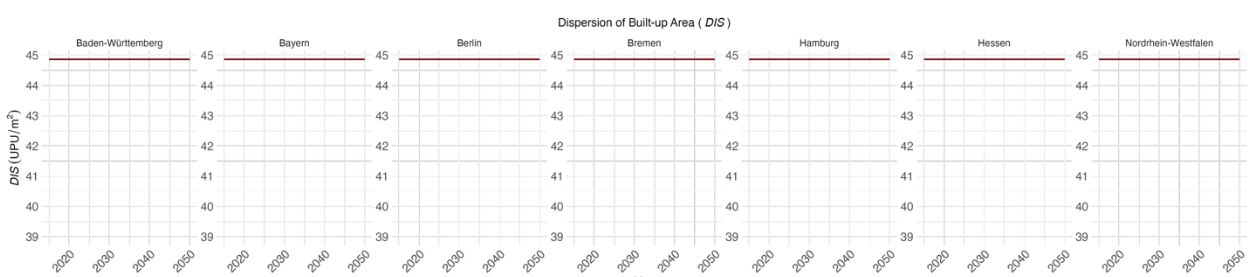

Figure 48 - Projected changes in DIS between 2015 – 2050 in Germany's federal states in scenario 5A

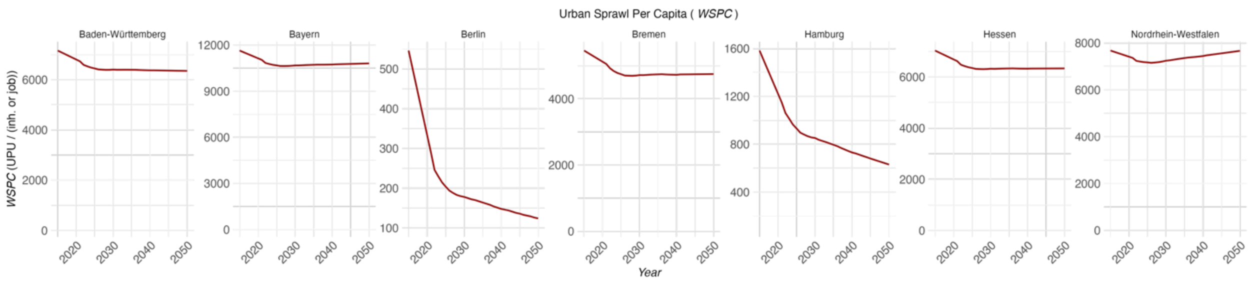

Figure 49 - Projected changes in WSPC between 2015 – 2050 in Germany's federal states in scenario 5A

Table 14 - Urban sprawl metrics for scenario 5A in 7 Germany's federal states with growing population

	WUP (UPU/m^2)			*LUP* (m^2/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
Federal States	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**
Baden-Württemberg	3.193	3.116	3.039	213.4	205.6	198.8	9.518	9.518	9.518	43.721	43.721	43.721
Bayern	3.103	3.069	3.055	289.8	277.7	273.2	7.724	7.724	7.724	44.325	44.325	44.325
Berlin	3.051	1.773	0.839	94.7	86.9	78.3	52.89	52.89	52.89	48.95	48.95	48.95
Bremen	13.649	12.992	12.474	157.4	153.1	149.9	39.37	39.37	39.37	48.16	48.16	48.16
Hamburg	5.913	4.551	2.749	113.1	106.7	96.9	42.26	42.26	42.26	48.74	48.74	48.74
Hessen	2.984	2.913	2.859	213.1	205.5	200.4	9.047	9.047	9.047	43.557	43.557	43.557
Nordrhein-Westfalen	5.74	5.628	5.736	193.8	189.6	193.7	14.494	14.494	14.494	46.391	46.391	46.391

4-4-6- Scenario 5B - Densification in states with shrinking population

This scenario is applied only to the nine regions with decreasing population. In these states, the built-up area is reduced by 1.25 times the relative reduction in the number of inhabitants and jobs between 2015 and 2050. However, in Schleswig-Holstein, the relative difference between the number of inhabitants and jobs in 2050 and 2015 was just 0.169%. Since multiplying this value by any factor below 2 did not yield a *WUP* value lower than that of scenario 2, a multiplier of 2 was applied instead.

All urban sprawl metrics decreased across these states. *WUP* showed an average decrease of 0.55 UPU/m² (−19.49%), with the largest drop observed in Saarland, where it declined from 6.636 in 2015 to 5.355 UPU/m² in 2050 (−1.28 UPU/m² decrease). *PBA* dropped by an average of 1.24 percentage points, again with Saarland showing the greatest decrease at 2.47 percentage points. *DIS* decreased by an average of 0.25 UPU/m² (−0.57%). *LUP* saw an average reduction of 16.21 m²/inh. or job (−4.44%), with Sachsen-Anhalt recording the largest decline at −41.04 m²/inh. or job. *WSPC* declined by an average of 969.02 UPU/inh. or job (−7.33%), with the sharpest drop again in Sachsen-Anhalt (−2,222.55 UPU/inh. or job decrease). The results for scenario 5B from 2015 to 2050 are presented in Figures 50-54, Table 15, and appendix D.

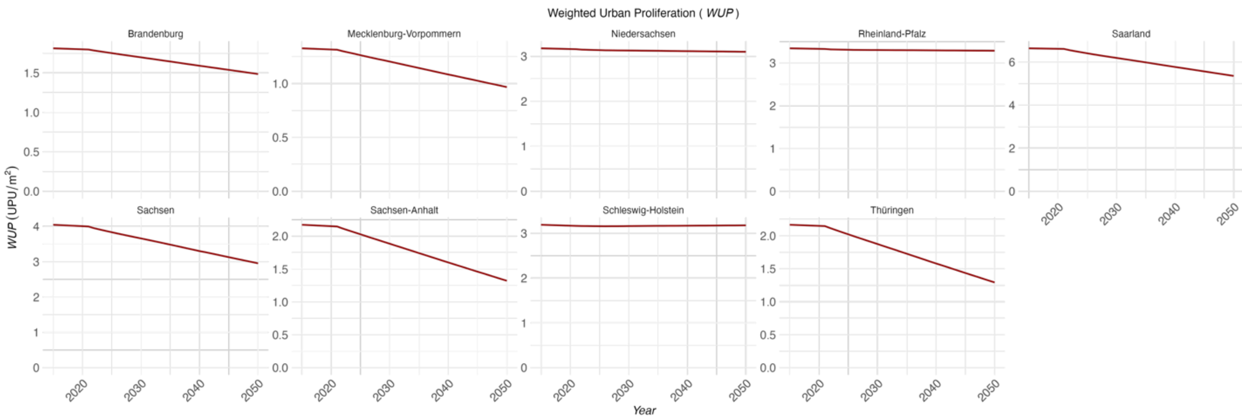

Figure 50 - Projected changes in WUP between 2015 – 2050 in Germany's federal states in scenario 5B

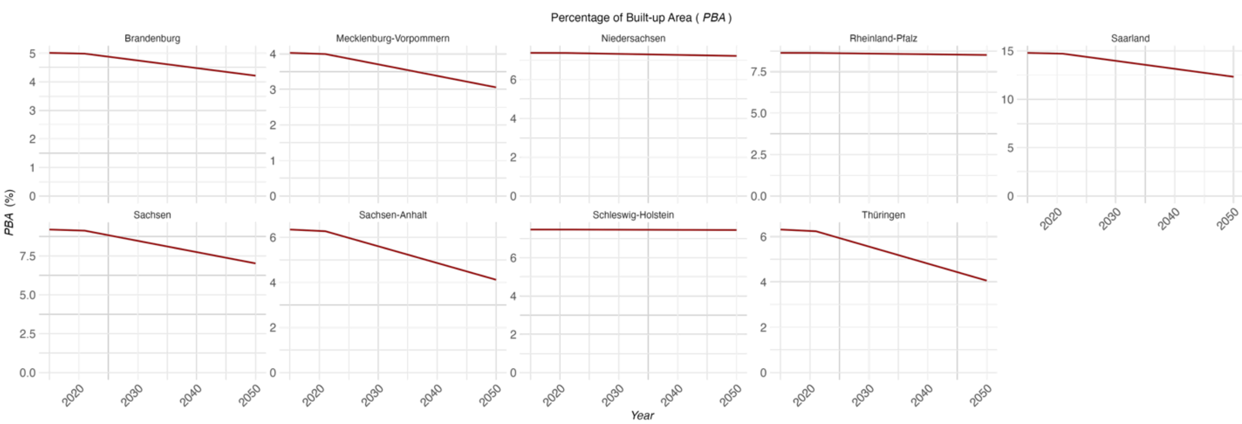

Figure 51 - Projected changes in PBA between 2015 – 2050 in Germany's federal states in scenario 5B

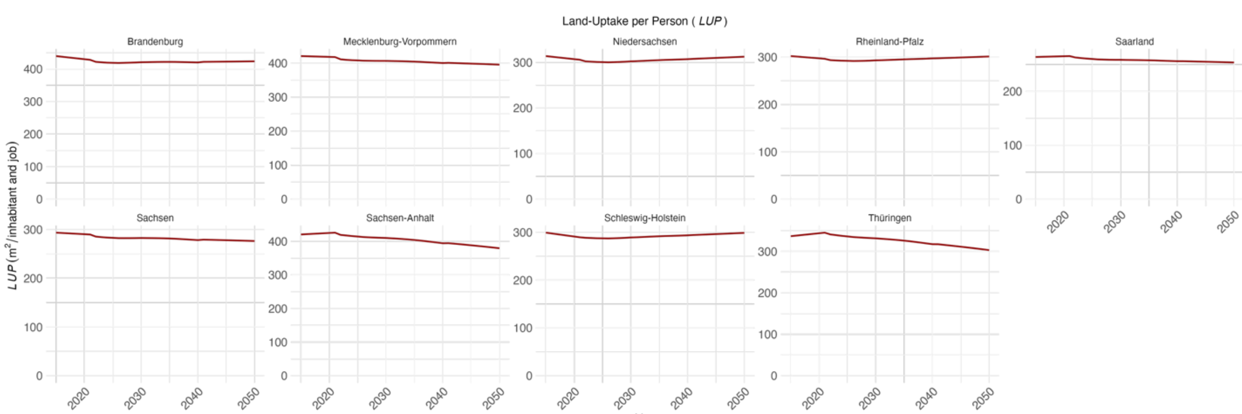

Figure 52 - Projected changes in LUP between 2015 – 2050 in Germany's federal states in scenario 5B

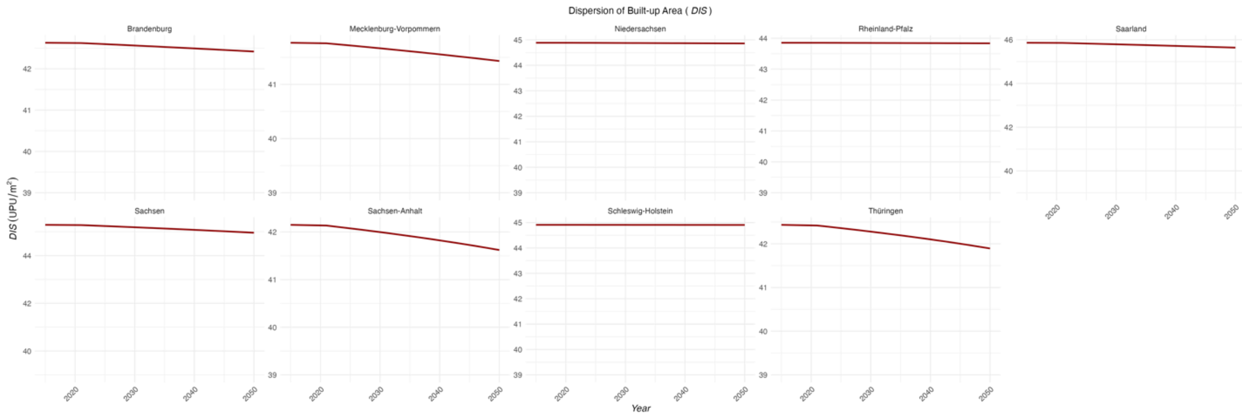

Figure 53 - Projected changes in DIS between 2015 – 2050 in Germany's federal states in scenario 5B

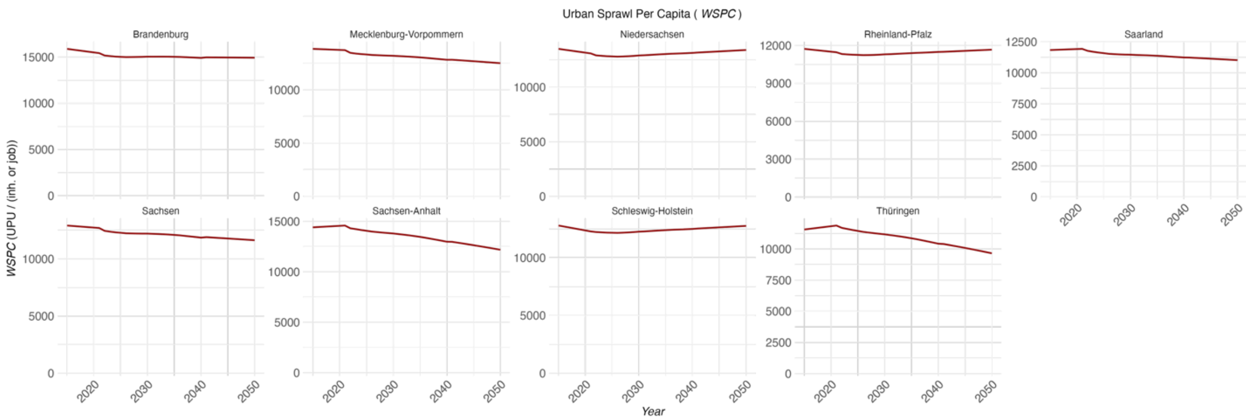

Figure 54 - Projected changes in WSPC between 2015 – 2050 in Germany's federal states in scenario 5B

Table 15 - Urban sprawl metrics for scenario 5B in the 9 Germany's federal states with shrinking population

	WUP (UPU/m^2)			*LUP* (m^2/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
Federal States	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**
Brandenburg	1.811	1.796	1.485	439.61	428.17	423.56	5.015	4.988	4.216	15876	15417	14920
Mecklenburg-Vorpommern	1.327	1.314	0.967	420.47	417.64	395.38	4.029	3.997	3.059	13849	13732	12504
Niedersachsen	3.178	3.159	3.101	313.95	305.93	312.60	7.382	7.377	7.226	13516	13101	13415
Rheinland-Pfalz	3.344	3.329	3.288	302.32	296.69	301.44	8.624	8.62	8.499	11724	11457	11662
Saarland	6.636	6.609	5.355	263.90	265.57	253.72	14.799	14.717	12.328	11834	11926	11020
Sachsen	4.044	3.996	2.953	293.53	289.76	276.40	9.193	9.121	7.018	12913	12696	11629
Sachsen-Anhalt	2.173	2.147	1.322	420.50	425.83	379.46	6.345	6.271	4.118	14402	14579	12179
Schleswig-Holstein	3.191	3.166	3.178	299.10	289.42	298.59	7.471	7.47	7.446	12775	12268	12744
Thüringen	2.167	2.147	1.293	336.72	345.21	303.06	6.316	6.241	4.061	11555	11874	9649

4-5- Analysis of reference scenarios at the regional level

4-5-1- Scenario 1 - Business as Usual (BAU)

In this scenario, by increasing the *LUP* in line with the observed trend between 1995 to 2015 (Figs. 55 & 56), *WUP* shows a steady increase across all PLRs, indicating a continuous expansion of urban sprawl. The average *WUP* value across all PLRs was 3.76 UPU/m² in 2015, rising to approximately 5.37 UPU/m² by 2050—representing a 42.6% increase over 35 years (Figs. 57 & 58).

PBA and *WSPC* also exhibit consistent upward trends. On average, *PBA* across all PLRs increased by 2.68 percentage points (28.3% increase in built-up area) from 2015 to 2050 (Figs. C-1 & C-2, Appendix C), while urban sprawl per capita (*WSPC*) rose by approximately 50% over the same period (Figs. C-5 & C-6, Appendix C) Although no major shift was expected in *DIS* values, it still showed a subtle upward trend. Due to the use of a uniform Y-axis starting point (for easier comparison) and the narrow value range of *DIS*, the visual impression in *DIS* figures may suggest very minor changes. However, in this case, the increase in *DIS* is in fact considerable (Figs. C-3 & C-4, Appendix C & D). Detailed values of urban sprawl metrics are presented in Table C-1 in Appendix C. Given their relevance, only the base year (2015), the first projection year (2021), and the target year (2050) are included.

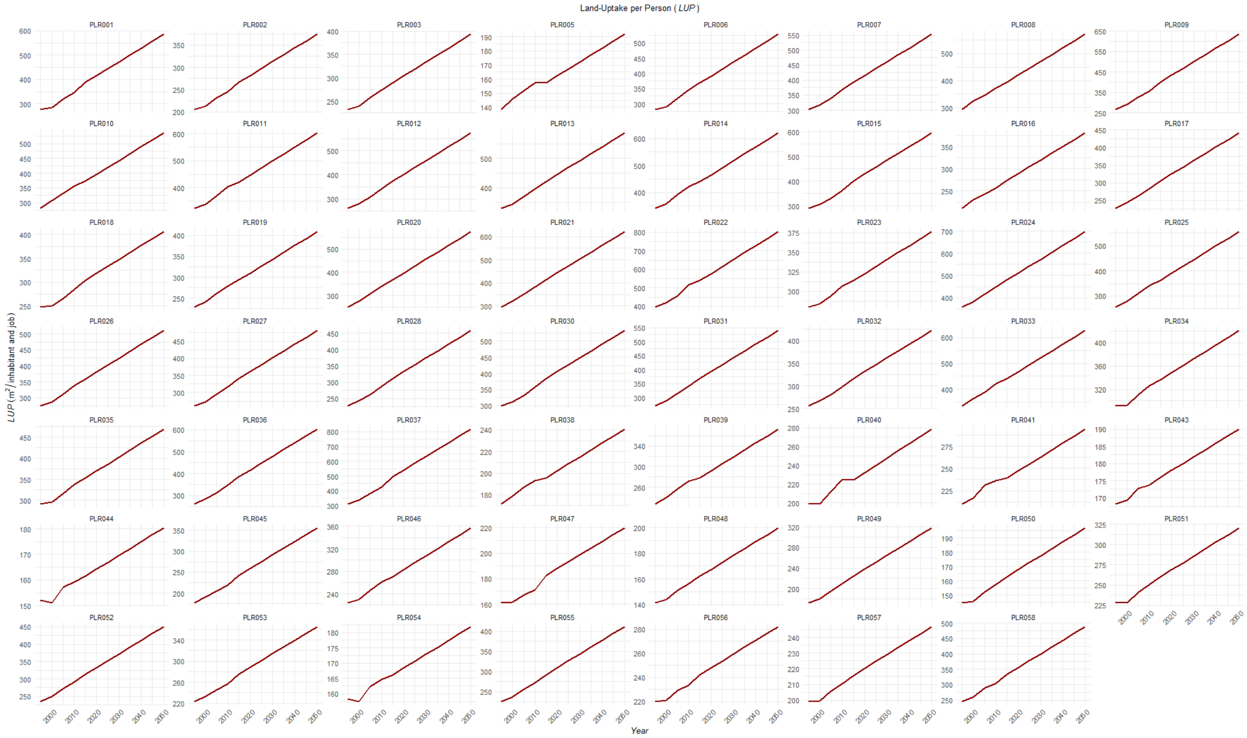

Figure 55 - Projected changes in LUP between 1995 – 2050 in scenario 1 (PLR001- PLR058)

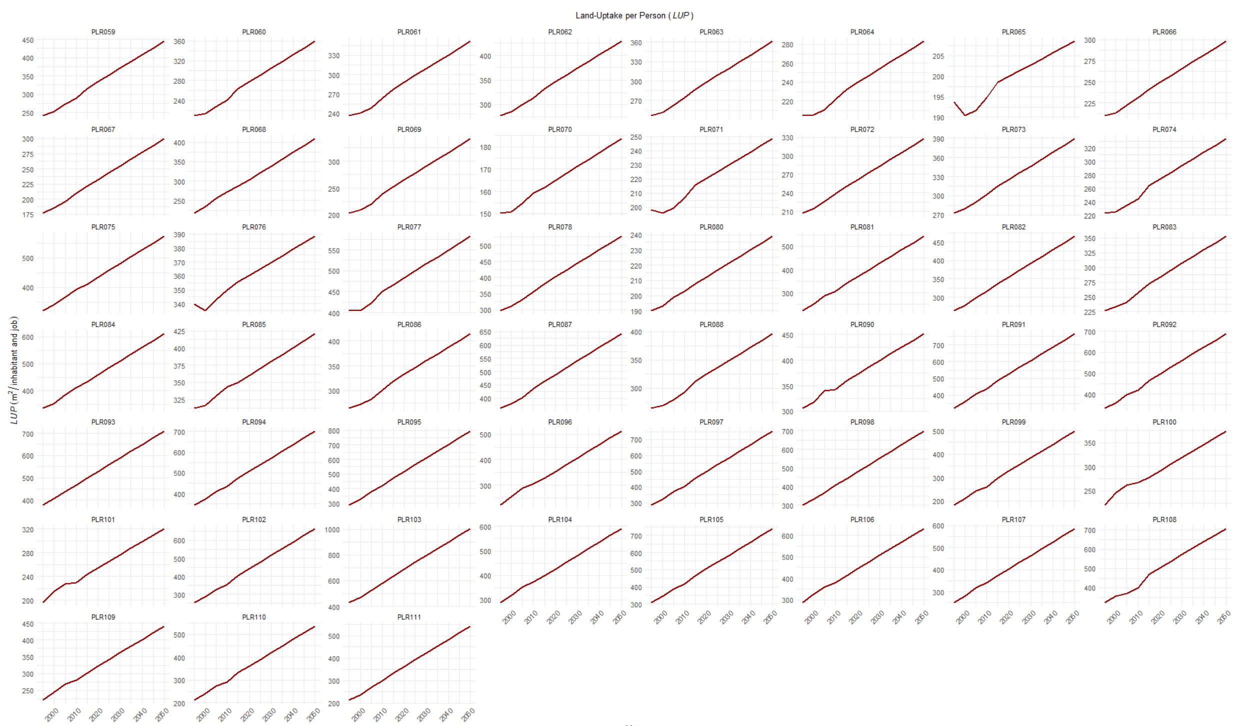

Figure 56 - Projected changes in LUP between 1995 – 2050 in scenario 1 (PLR059- PLR111)

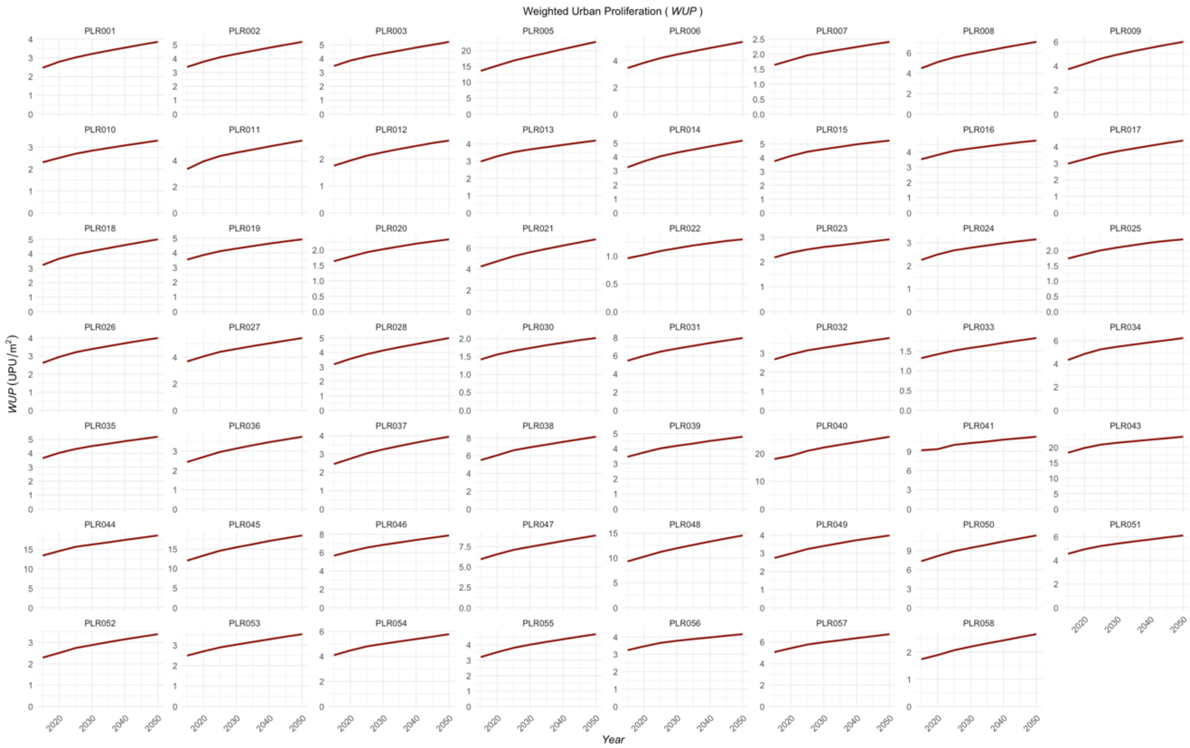

Figure 57 - Projected changes in WUP between 2015 – 2050 in scenario 1 (PLR001- PLR058)

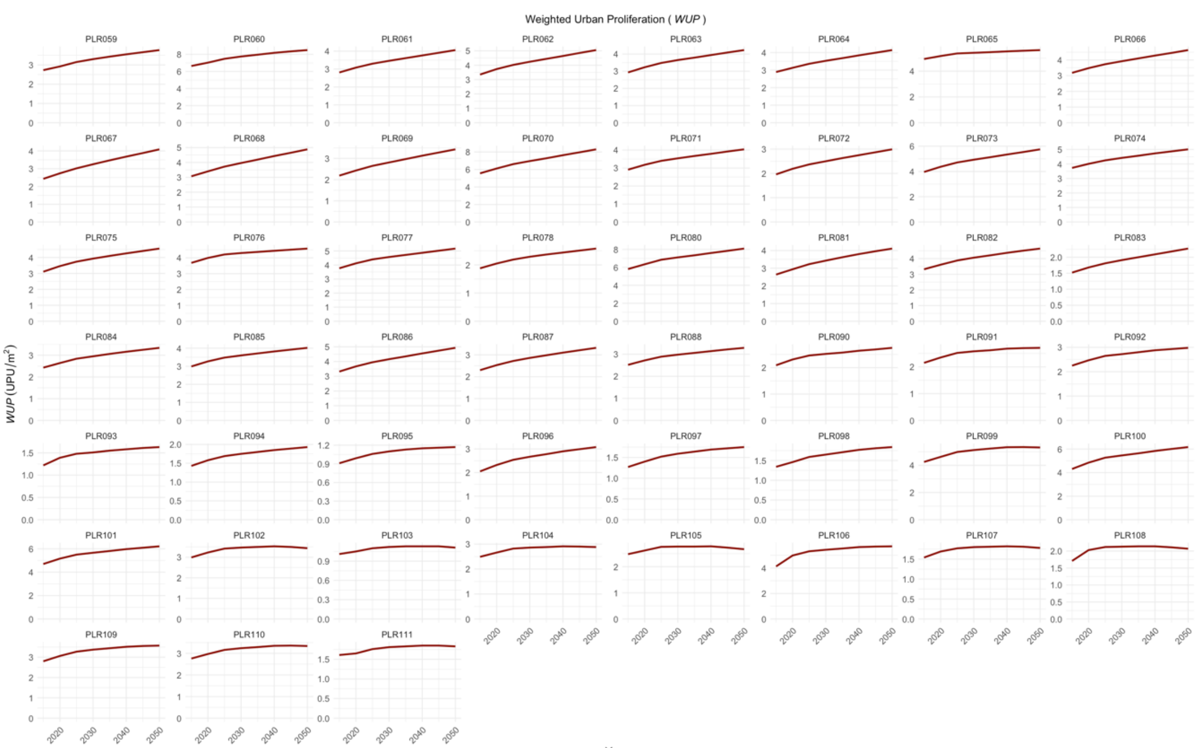

Figure 58 - Projected changes in WUP between 2015 – 2050 in scenario 1 (PLR059- PLR111)

4-5-2- Scenario 2 – Constant *LUP*

In this scenario, land uptake per person remains at the value as it was in 2015 (Figs. 59 & 60). Three main *WUP* behavior patterns are observed (Fig. 61 & 62). First, in the majority of PLRs, *WUP* increases from 2015 until around 2025, followed by a gradual decline by 2050 (e.g., PLR001, PLR002, and PLR003). Second, some PLRs exhibit a steady decrease in *WUP* throughout the entire period (e.g., PLR110 and PLR111). Third, a smaller group of PLRs shows a consistent increase in *WUP* from 2015 to 2050 (e.g., PLR004 and PLR054). Overall, 65 PLRs (around 59.63%) experienced a decrease in *WUP* between 2015 and 2050. This trend is largely attributed to a decline in population and job numbers over time in many regions of Germany. In other words, in PLRs with a declining population, maintaining a constant *LUP* over time leads to a slight decrease in urban sprawl, whereas in regions with population growth, the same approach results in an increase in urban sprawl. On average, across all PLRs, *WUP* decreased by approximately 0.05 UPU/m², representing a change of 1.37% over the 35-year period.

Trends in *PBA*, *DIS*, and *WSPC* show notable alignment with the patterns observed in *WUP*. Among all 109 PLRs, 65 experienced a decrease in *PBA*, *DIS*, and *WSPC* between 2015 and 2050, while 44 showed an increase in all three metrics. On average, *PBA* increased slightly by 0.014 percentage points, while *DIS* declined by approximately 0.06 UPU/m² (−0.14%), and *WSPC* decreased by about 102 UPU/ inh. or job, corresponding to a change of 0.8%. The results for scenario 2 from 2015 to 2050 are presented in Figures 58-61, Appendix C (Figs. C-7 to C12 & Tab. C2), and Appendix D.

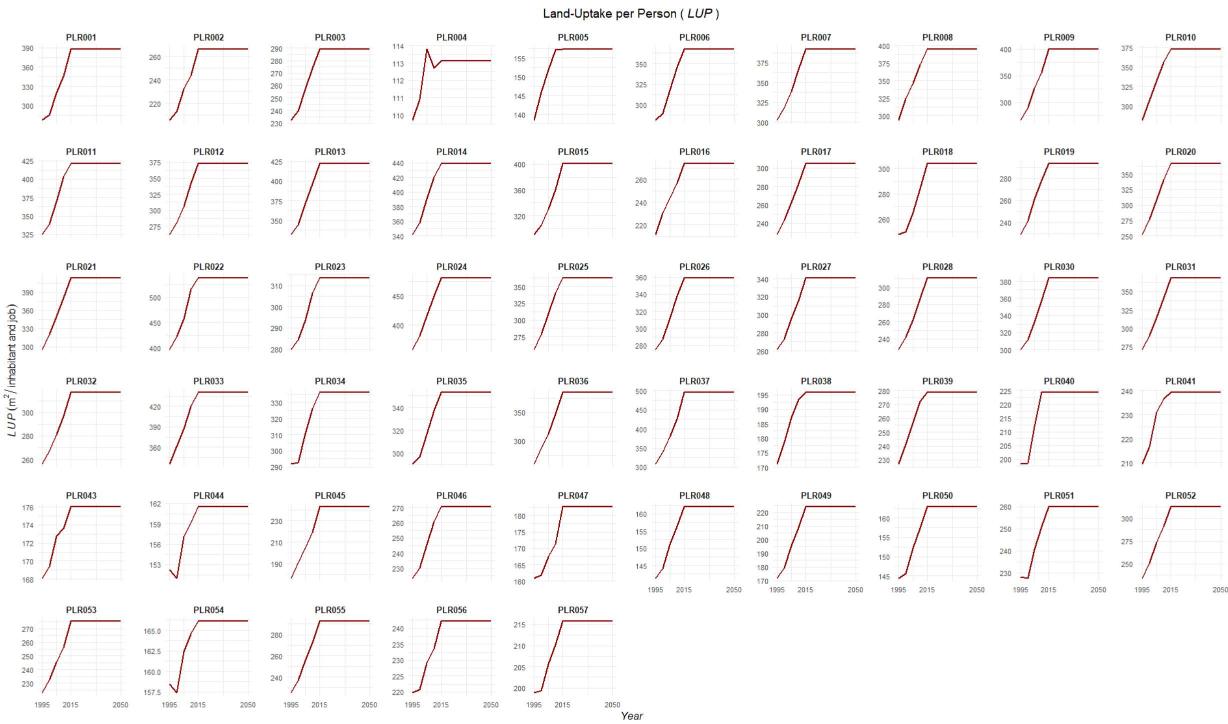

Figure 59 – Projected changes in LUP between 1995 – 2050 in scenario 2 (PLR001- PLR057)

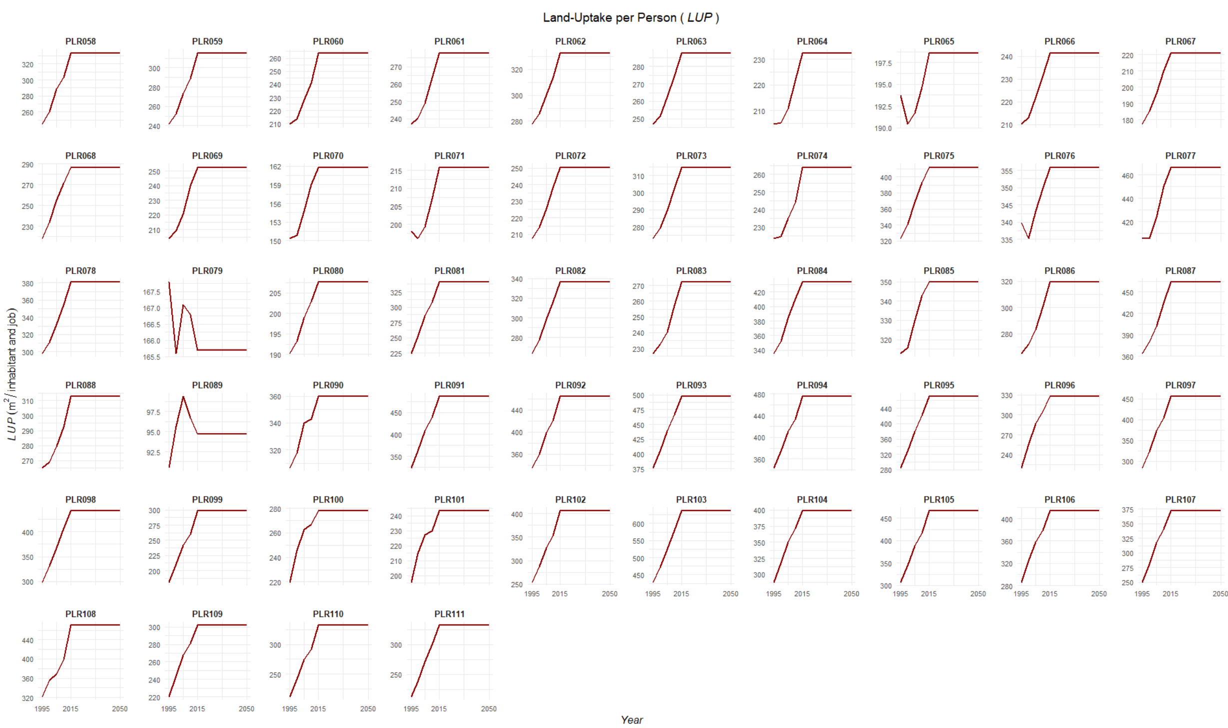

Figure 60 - Projected changes in LUP between 1995 – 2050 in scenario 2 (PLR058- PLR111)

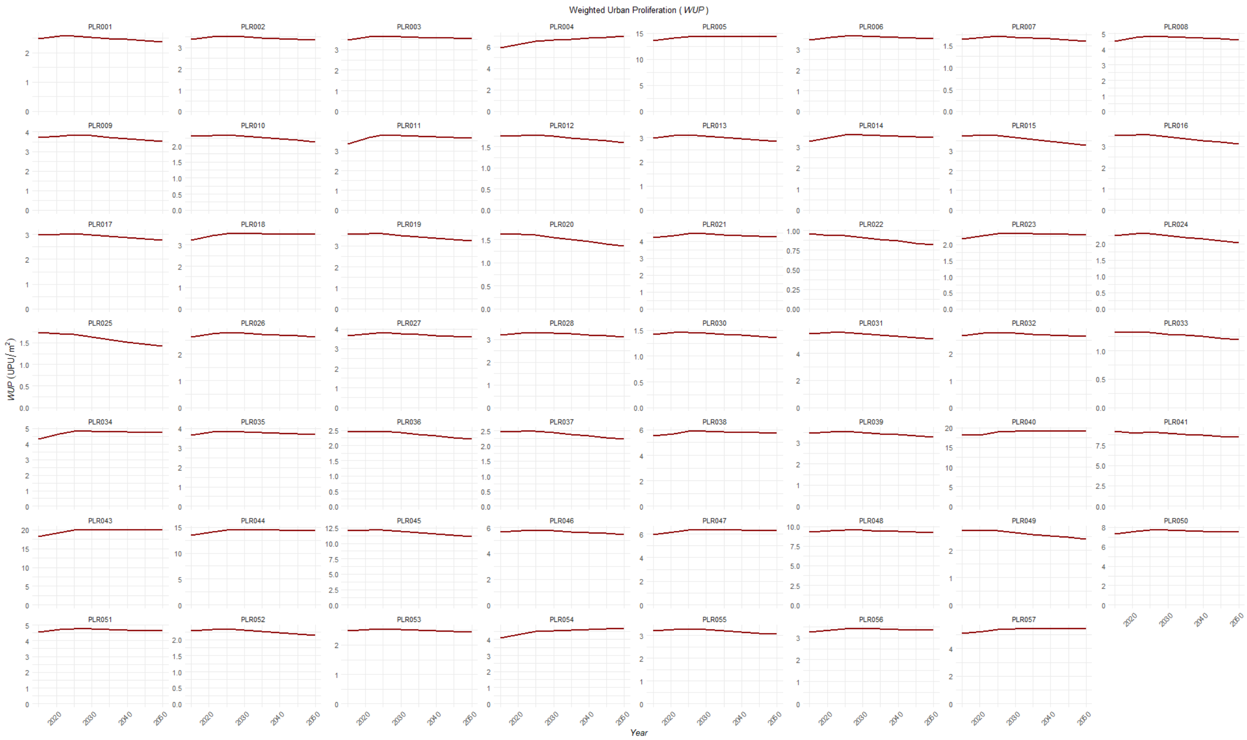

Figure 61 - Projected changes in WUP between 2015 – 2050 in scenario 2 (PLR001- PLR057)

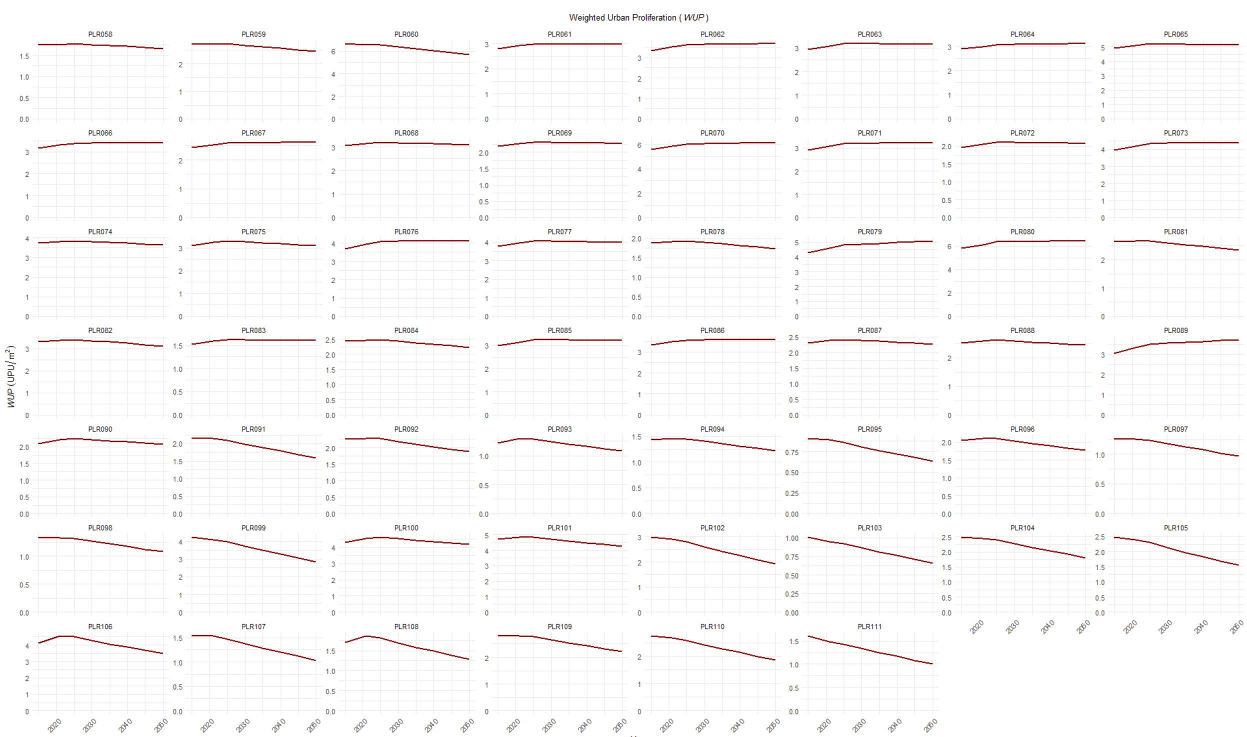

Figure 62 - Projected changes in WUP between 2015 – 2050 in scenario 2 (PLR058- PLR111)

4-5-3- Scenario 3 - *WUP* mirrors population and employment trends

WUP trends in scenario 3 show a general decline across most planning regions (Figs. 63 & 64). Between 2015 and 2050, 65 PLRs experienced a decrease in *WUP*, with an average reduction of approximately 0.289 UPU/ m^2 (−11.14%), while 44 PLRs showed an increase, averaging about 0.313 UPU/ m^2 (+6.34%). The PLRs with upward *WUP* trend are the ones with increasing population and the PLRs with downward *WUP* trend, are the ones with decreasing population.

The 65 PLRs that had a decline in *WUP,* experienced a decrease in both *PBA* and *DIS*, while the other 44 PLRs showed an increase. In contrast, *LUP* increased in 64 PLRs and decreased in 45 (Figs. C-13 to C-18, Appendix C). The changes in *PBA*, *DIS*, and *LUP* are minor (Tab. C-3). On average, *PBA* declined slightly by 0.50 percentage points, while *DIS* dropped by approximately 0.11 UPU/m² (−0.26%). *LUP* increased moderately by 4.91 m^2/ (inh. or job), corresponding to a 1.51% rise. *WSPC* remained unchanged across all PLRs during the period because the relative changes in the value of *WUP* and the n umber of inhabitants and jobs are the same (Figs. C-19 & C-20, Appendix C).

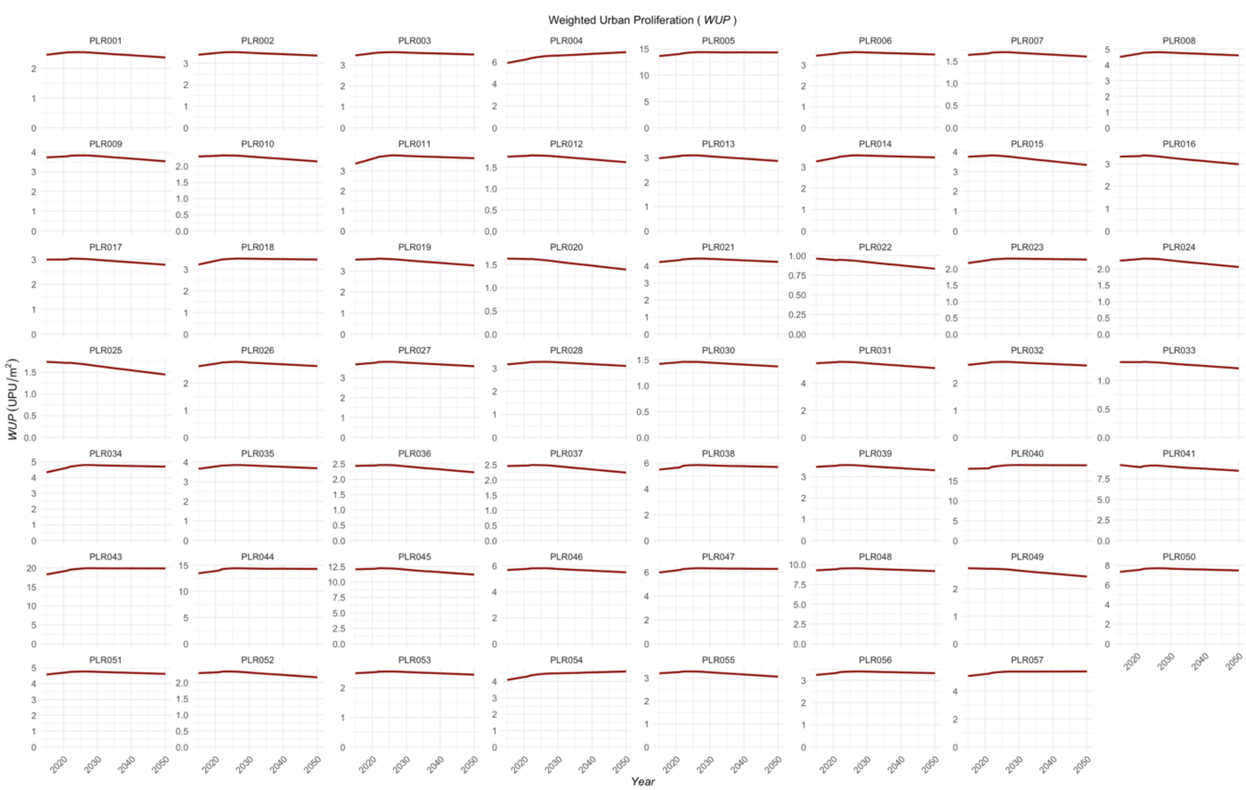

Figure 63 – Projected changes in WUP between 2015 – 2050 in scenario 3 (PLR001- PLR057)

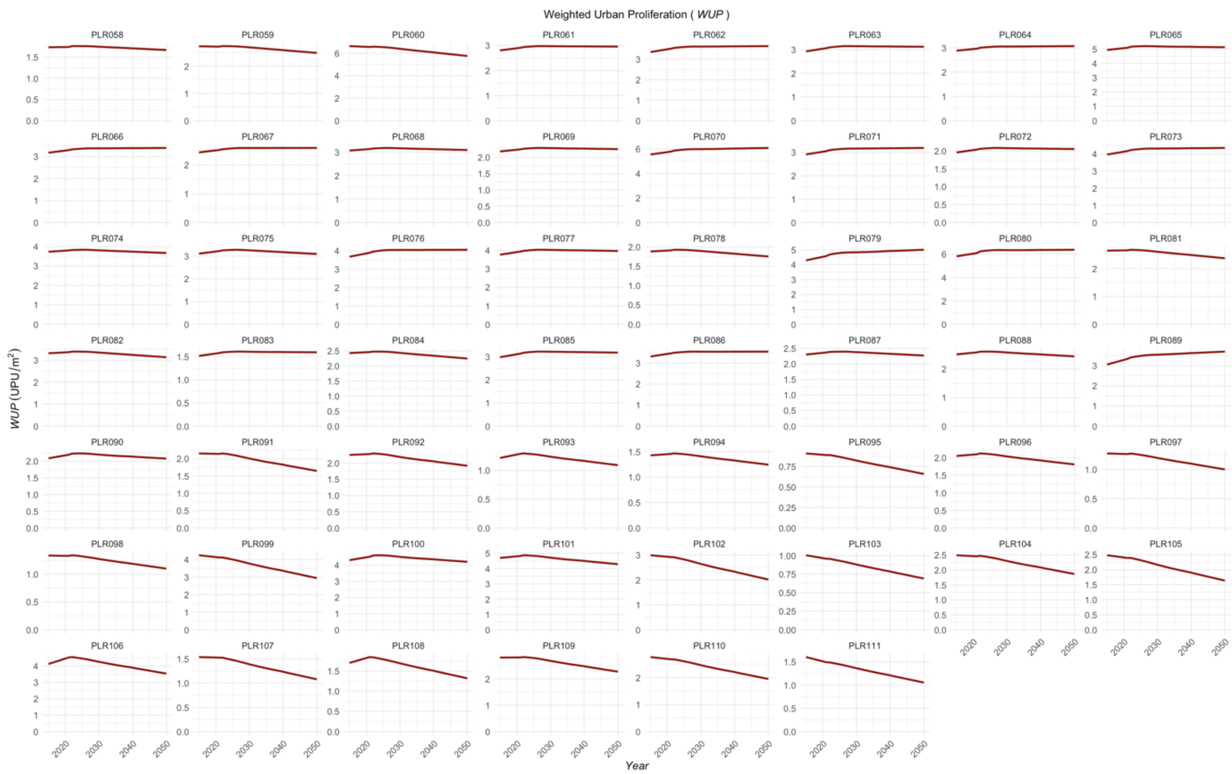

Figure 64 - Projected changes in WUP between 2015 – 2050 in scenario 3 (PLR058- PLR111)

4-5-4- Scenario 4 – Constant urban sprawl

In this scenario, by keeping *WUP* constant (Figs. 65 & 66), the 44 PLRs in which the number of inhabitants and jobs increased between 2015 and 2050, *PBA* rose on average by 0.62 percentage points (Figs. C-21 & C-22, Appendix C). In this group, *DIS* also experienced a slight increase of approximately 0.03 UPU/m² (+0.06%). At the same time, *LUP* declined by 10.0 m²/ (inh. or job) (−3.65%). While in most PLRs, the changes in these metrics were minor (Tab. C-4, Figs. C-23 to C-26, Appendix C), a few regions experienced sharper increases. For example, PLR089 (Berlin) had a *PBA* of 52.9% in 2015, which increased steadily to 62.2% by 2050.

The 65 PLRs in which the number of inhabitants and jobs declined, showed a slight average decrease of 0.09 percentage points in *PBA*. Meanwhile, *LUP* increased by 51.0 m²/ inh. or job (+12.67%). *DIS* in these areas declined only slightly, by 0.02 UPU/m² on average (−0.05%).

A pattern similar to *LUP* is observed in *WSPC* (Figs. C-27 & C-28, Appendix C). In the 44 PLRs in which the number of inhabitants and jobs increased, *WSPC* decreased on average by 540.8 UPU/ (inh. or job) (−5.8%). Conversely, in the 65 PLRs where population and jobs declined, *WSPC* increased significantly, with an average rise of 2018.8 UPU/ (inh. or job) (+14.0%). PLR105 (Anhalt-Bitterfeld-Wittenberg) experienced a large increase of 9034 UPU/ (inh. or job) between 2015 and 2050.

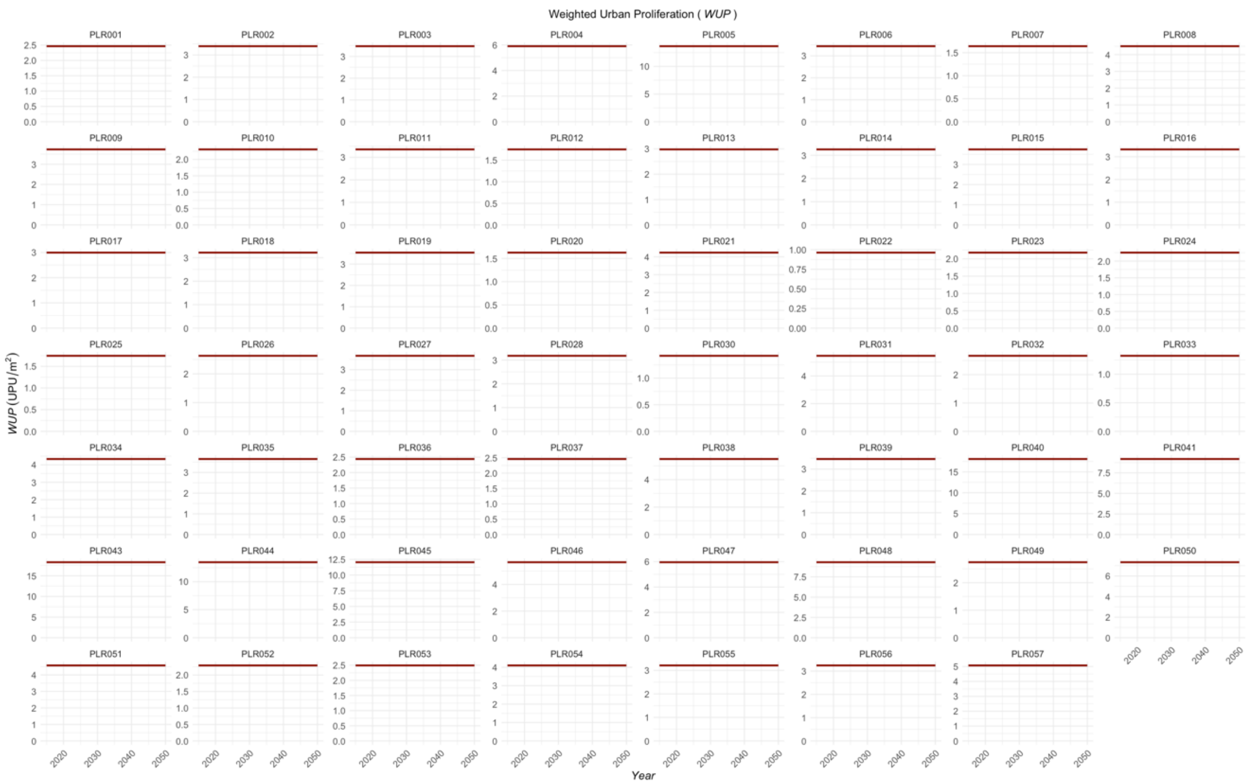

Figure 65 - Projected changes in WUP between 2015 – 2050 in scenario 4 (PLR001- PLR057)

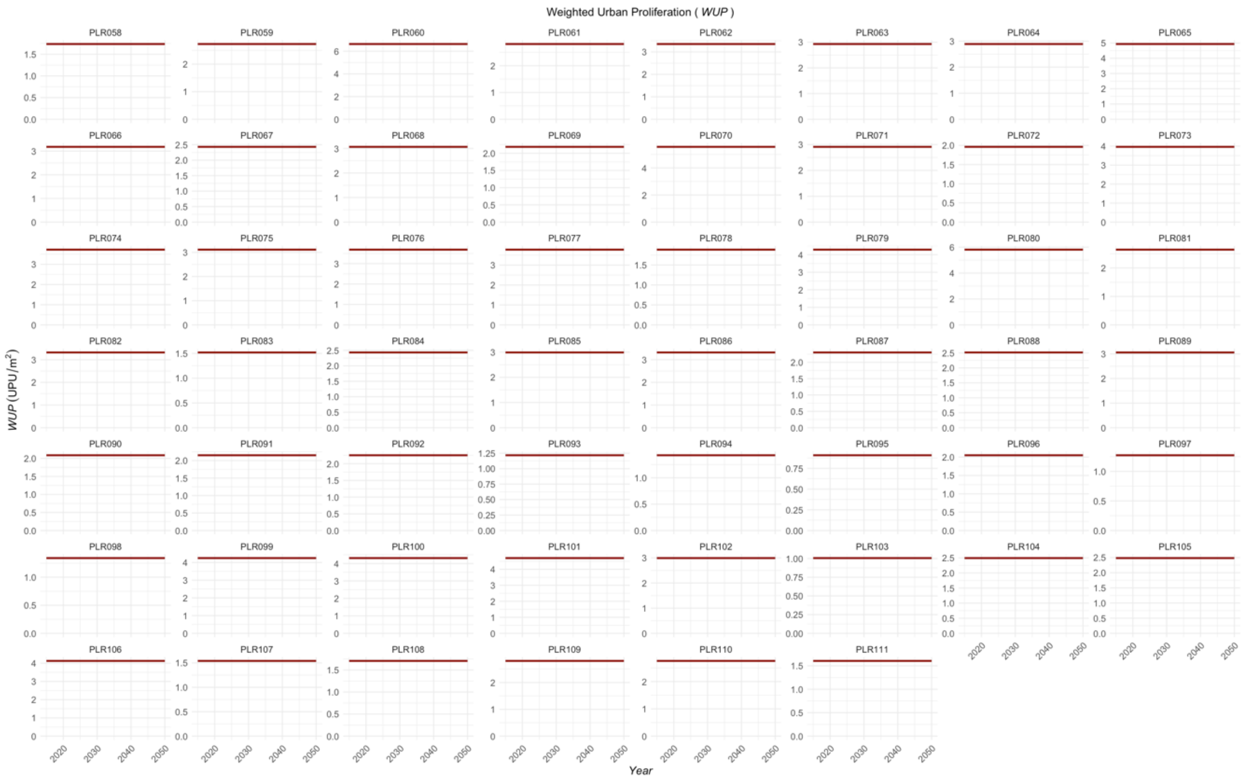

Figure 66 - Projected changes in WUP between 2015 – 2050 in scenario 4 (PLR058- PLR111)

4-5-5- Scenario 5A - Densification in regions with growing population

For scenario 5A, only planning regions with a positive population-job change were considered. In all 65 selected planning regions, the *WUP* value decreased (Fig. 67). On average, the decrease in urban sprawl levels across these regions is by approximately 13%. PLR089 (Berlin) and PLR004 (Hamburg) experienced the greatest reductions in *WUP* values between 2015 and 2050, by 72.5% (−2.21 UPU/m² decrease) and 53.5% (−3.16 UPU/m² decrease), respectively. These two city-states are among the regions with the highest population growth. In contrast, in regions where population growth was less pronounced, the reduction in *WUP* was also less noticeable.

Since the built-up area remained constant, *PBA* did not change (Fig. 68). Consequently, as *DIS* is calculated as a function of *PBA*, the *DIS* value also remained unchanged (Fig. C-30, Appendix C & D). The *LUP* level decreased in all regions by 2050; on average, there was a 14 m²/ inh. or job reduction (-5.8% decrease) across all regions (Fig. C-29, Appendix C). *WSPC* also decreased significantly, with an average reduction of 803 UPU/ (inh. or job) (-11.5% decrease, Fig. C-31, Appendix C). Even in regions where *WUP* decreased only slightly, the reduction in

WSPC was much more noticeable, as *WSPC* is more sensitive to population changes. Overall, in scenario 5A, every single metric of urban sprawl either remained constant or decreased by 2050 (Tab. C-5, Appendix C).

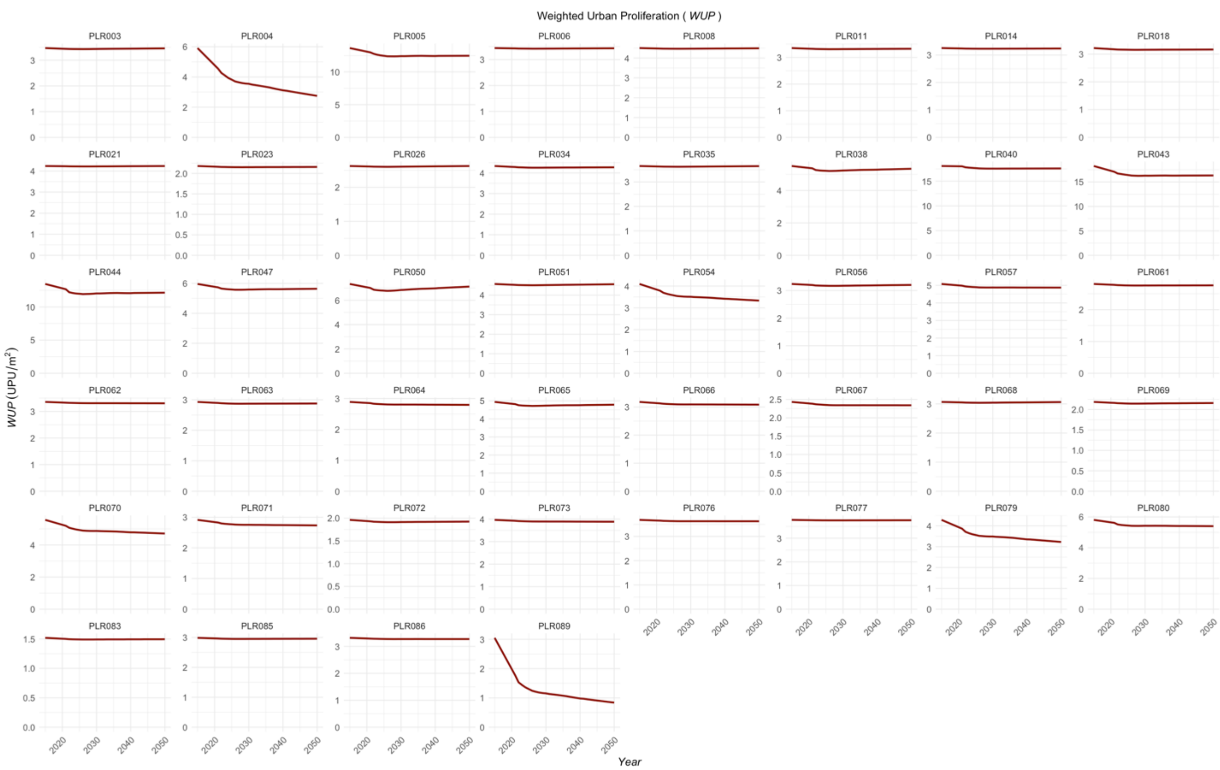

Figure 67 – Projected changes in WUP between 2015 – 2050 in scenario 5A

Figure 68 - Projected changes in PBA between 2015 – 2050 in scenario 5A

4-5-6- Scenario 5B - Densification in regions with shrinking population

In this scenario, the built-up area in shrinking regions decreased by 1.25 times the percentage reduction in the number of inhabitants and jobs (Fig. 70). On average, *WUP* decreased by 0.41 UPU/m², corresponding to a 15.7% reduction (Fig. 69). Since the built-up area decreased, both *PBA* and *DIS* levels also declined across all regions. *PBA* showed an average reduction of 0.9 percentage points (equivalent to an average 13.9% reduction in built-up area), with this reduction occurring smoothly over the years. Similarly, *DIS* decreased by an average of 0.20 UPU/m², corresponding to a 0.5% decline (Fig. C-33, Appendix C & D).

LUP values generally decreased as well. while some regions experienced a slight increase in *LUP* in the first period (for example, PLR105 between 2015 and 2021), the overall trend by 2050 was downward. These temporary increases in *LUP* occurred where the rate of population and job decline exceeded the rate of built-up area reduction. On average, *LUP* decreased by 13.9 m²/ inh. or job, corresponding to a 3.5% reduction (Fig. C-32, Appendix C).

While *WSPC* generally declined across all regions by an average of 824.1 UPU/ (inh. or job) (-5.8% decrease), a few PLRs exhibited a more complex pattern. For example, in PLR048, *WSPC* decreased sharply between 2015 and 2026 from 5816 to 5365 UPU/ (inh. or job) due to an initial increase in population and jobs combined with a reduced built-up area, but when population and jobs began to decline steadily and the built-up area decreased by a very small amount (1.3% in total), *WSPC* started to rise again. However, the value in 2050 is still smaller than 2015 (5816 to 5770 UPU/ (inh. or job)). wherever the rate of population and job decline exceeds the rate of built-up area reduction, *WSPC* tends to stabilize or even increase, rather than continuing to decline (Fig. C-34, Appendix C). Overall, in scenario 5A and 5B every single metric of urban sprawl decreased by 2050 (Tab. C-6, Appendix C).

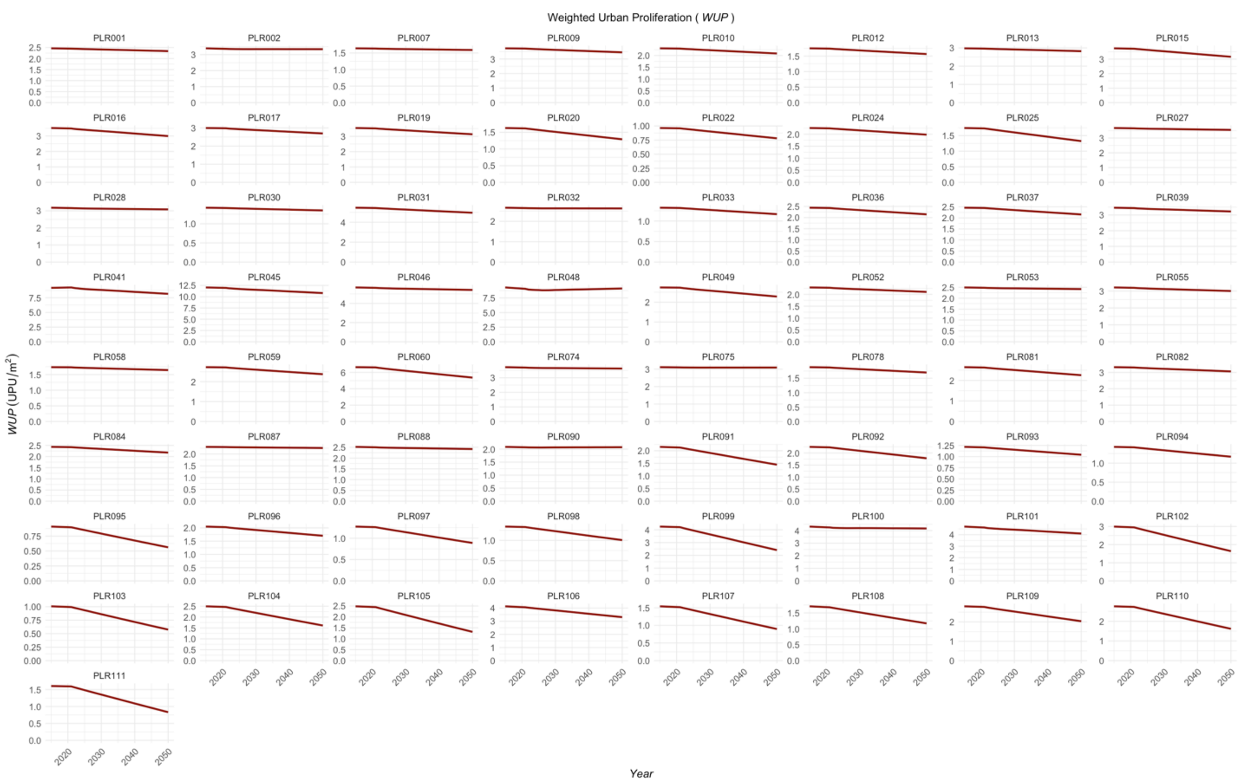

Figure 69 - Projected changes in WUP between 2015 – 2050 in scenario 5B

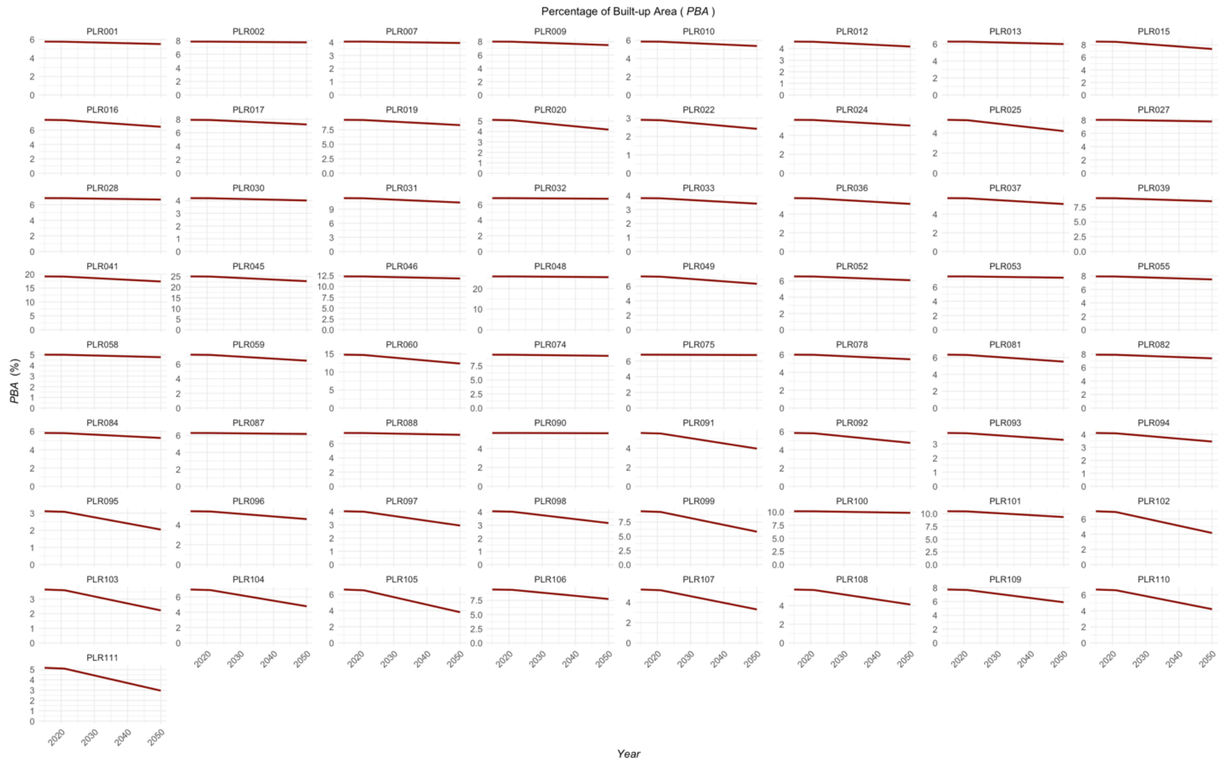

Figure 70 - Projected changes in PBA between 2015 – 2050 in scenario 5B

4-6- Targets, Limits, and Warning Values at the Regional level

Given the influence of population change on *WUP*, PLRs were categorized into two groups, following the model of scenarios 5A and 5B. For PLRs with increasing population (P2050 – P2015 > 0), scenario 5A is used as the target. This choice reflects their moderate average population growth (6.3%), with PLR089 and PLR004 showing higher increases (21% and 16%, respectively). In these cases, maintaining constant *PBA* is considered realistic rather than too ambitious. Scenario 4 (constant urban sprawl) defines the no-deterioration zone, and the limit value is between scenarios 4 and 5A. The warning value is set halfway between the no-deterioration zone and scenario 3. Results for each PLR are given in Table 16.

Table 16 - Proposed targets, limits, no-deterioration, and warning values for Germany's PLRs with increasing population

	WUP **(UPU/m²)**				***PBA*** **(%)**				***LUP*** **(m²/ (inh. or job))**				***WSPC*** **(UPU/ (inh. or job))**			
PLR	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target
PLR003	3.494	3.471	3.465	3.459	8.225	8.189	8.180	8.171	287.43	286.2	285.87	285.53	12208	12128	12109	12089
PLR004	6.394	5.901	4.325	2.749	48.448	47.811	45.034	42.257	111.07	109.6	103.25	96.89	1466	1353	992	630
PLR005	13.999	13.655	13.064	12.474	40.900	40.566	39.967	39.368	155.68	154.4	152.13	149.85	5329	5198	4973	4748
PLR006	3.471	3.441	3.437	3.433	7.319	7.277	7.267	7.257	364.71	362.6	362.12	361.63	17298	17149	17130	17110
PLR008	4.554	4.504	4.499	4.493	9.227	9.157	9.144	9.130	390.56	387.6	387.03	386.45	19274	19063	19041	19018
PLR011	3.488	3.352	3.339	3.325	7.209	6.998	6.977	6.957	403.70	391.9	390.75	389.59	19535	18771	18697	18622
PLR014	3.349	3.256	3.247	3.239	7.363	7.213	7.197	7.182	425.99	417.3	416.42	415.53	19375	18836	18790	18743
PLR018	3.333	3.217	3.192	3.166	8.011	7.833	7.785	7.737	293.62	287.1	285.34	283.57	12215	11792	11699	11605
PLR021	4.241	4.236	4.236	4.236	8.605	8.609	8.598	8.588	413.71	413.9	413.39	412.87	20389	20368	20368	20367
PLR023	2.235	2.180	2.169	2.159	5.917	5.819	5.801	5.782	305.57	300.5	299.55	298.6	11543	11260	11204	11148
PLR026	2.629	2.627	2.627	2.627	5.711	5.712	5.707	5.702	358.94	359	358.70	358.4	16527	16513	16512	16510
PLR034	4.518	4.337	4.306	4.275	9.29	9.037	8.979	8.922	322.98	314.2	312.19	310.18	15708	15078	14970	14862
PLR035	3.665	3.651	3.649	3.647	8.371	8.342	8.345	8.347	351.33	350.1	350.24	350.37	15386	15326	15318	15310
PLR038	5.609	5.508	5.425	5.341	14.789	14.658	14.558	14.458	193.23	191.5	190.21	188.92	7329	7198	7089	6979
PLR040	18.525	18.081	17.837	17.593	37.974	37.501	37.166	36.831	220.44	217.7	215.75	213.8	10754	10496	10355	10213
PLR043	19.066	18.277	17.305	16.334	46.458	45.72	44.702	43.683	172.32	169.6	165.81	162.02	7072	6779	6419	6058
PLR044	13.884	13.470	12.812	12.154	38.020	37.638	36.970	36.302	159.31	157.7	154.92	152.13	5819	5645	5369	5093
PLR047	6.108	5.958	5.799	5.639	16.235	16.086	15.881	15.677	180.07	178.4	176.14	173.88	6775	6609	6432	6255
PLR050	7.410	7.340	7.231	7.123	21.592	21.527	21.403	21.278	162.2	161.7	160.77	159.84	5566	5513	5432	5350
PLR051	4.593	4.573	4.566	4.559	10.257	10.228	10.219	10.211	258.85	258.1	257.90	257.69	11591	11541	11523	11505
PLR054	4.358	4.099	3.717	3.334	14.610	14.331	13.846	13.360	161.27	158.2	152.83	147.46	4810	4524	4102	3680
PLR056	3.282	3.241	3.224	3.206	9.219	9.16	9.124	9.088	239.56	238	237.10	236.19	8529	8424	8379	8333
PLR057	5.241	5.078	4.975	4.872	13.579	13.373	13.218	13.063	210.7	207.5	205.09	202.67	8131	7878	7718	7558
PLR061	2.885	2.809	2.787	2.766	7.3855	7.254	7.226	7.199	270.41	265.6	264.59	263.58	10563	10285	10206	10127
PLR062	3.500	3.354	3.329	3.303	9.202	8.952	8.897	8.841	318.57	309.9	307.98	306.06	12116	11612	11524	11435
PLR063	3.026	2.929	2.904	2.878	8.257	8.086	8.042	7.997	278.38	272.6	271.13	269.66	10205	9876	9791	9705
PLR064	2.983	2.889	2.842	2.795	8.271	8.142	8.053	7.964	226.64	223.1	220.67	218.23	8175	7916	7788	7659
PLR065	5.029	4.935	4.860	4.784	14.515	14.406	14.282	14.158	196.16	194.7	193.01	191.32	6795	6668	6567	6465
PLR066	3.288	3.180	3.132	3.084	9.731	9.548	9.467	9.385	234.31	229.9	227.94	225.98	7918	7657	7542	7426
PLR067	2.509	2.431	2.386	2.341	8.0935	7.967	7.886	7.804	215.58	212.2	210.04	207.88	6682	6476	6356	6236
PLR068	3.078	3.067	3.064	3.062	8.5875	8.562	8.563	8.564	285.36	284.5	284.55	284.59	10228	10192	10183	10174
PLR069	2.221	2.186	2.172	2.159	7.2475	7.17	7.152	7.133	248.26	245.6	244.98	244.36	7610	7487	7442	7396
PLR070	5.825	5.557	5.133	4.709	19.332	19.04	18.537	18.035	158.19	155.8	151.69	147.57	4767	4547	4200	3853
PLR071	3.052	2.913	2.823	2.733	8.695	8.494	8.361	8.227	208.21	203.4	200.21	197.01	7309	6976	6761	6545
PLR072	2.010	1.962	1.943	1.924	5.2745	5.201	5.170	5.138	244.93	241.5	240.07	238.63	9333	9110	9022	8934
PLR073	4.156	3.963	3.923	3.882	10.310	9.988	9.921	9.855	299.97	290.6	288.65	286.7	12092	11529	11412	11295
PLR076	3.874	3.684	3.655	3.626	9.317	9.004	8.949	8.893	337.87	326.5	324.52	322.54	14049	13360	13256	13152

PLR077	3.875	3.774	3.766	3.759	8.0285	7.883	7.858	7.833	453.75	445.5	444.11	442.72	21900	21330	21287	21244
PLR079	4.643	4.287	3.757	3.227	14.678	14.311	13.689	13.067	159.67	155.7	148.92	142.13	5051	4664	4087	3510
PLR080	6.088	5.808	5.604	5.399	14.983	14.648	14.385	14.123	200.99	196.5	192.98	189.46	8167	7791	7517	7243
PLR083	1.558	1.519	1.507	1.496	4.309	4.245	4.222	4.199	265.86	261.9	260.50	259.09	9611	9374	9302	9229
PLR085	3.085	2.987	2.972	2.957	7.2395	7.08	7.052	7.025	338.43	331	329.70	328.39	14422	13962	13892	13822
PLR086	3.436	3.320	3.297	3.275	7.308	7.141	7.103	7.065	308.85	301.8	300.18	298.56	14521	14031	13935	13839
PLR089	3.382	3.060	1.949	0.839	62.985	62.224	57.558	52.893	93.205	92.1	85.18	78.25	501	453	289	124

For PLRs with decreasing population (P2050 – P2015 < 0), scenario 5B serves as the target. This group comprises 65 regions with an average population decline of 11%, and 5 regions experiencing a decrease exceeding 30%. The limit is set at scenario 2, while the no-deterioration zone remains at scenario 4. For the warning value, although the midpoint between scenario 1 (the most unsustainable) and scenario 4 was considered, it proved too low. Instead, a value approximately 20% above scenario 4, and 80% below scenario 1 is used as a more appropriate threshold. Results for these PLRs are presented in Table 17.

Table 17 - Proposed targets, limits, no-deterioration, and warning values for Germany's PLRs with decreasing population

PLR	***WUP*** **(UPU/m^2)**				***PBA*** **(%)**				***LUP*** **(m^2/ (inh. or job))**				***WSPC*** **(UPU/ (inh. or job))**			
	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target
PLR001	2.742	2.465	2.366	2.338	6.300	5.777	5.566	5.513	439.3	402.8	388.1	384.4	19124	17191	16497	16306
PLR002	3.760	3.396	3.354	3.341	8.502	7.892	7.800	7.778	290.6	269.8	266.6	265.9	12851	11608	11465	11420
PLR007	1.794	1.641	1.601	1.590	4.357	4.051	3.967	3.945	431.1	400.8	392.4	390.2	17751	16231	15839	15732
PLR009	4.189	3.733	3.516	3.457	8.773	7.964	7.587	7.482	462.6	420.0	400.1	394.5	22089	19685	18543	18230
PLR010	2.505	2.306	2.134	2.087	6.241	5.836	5.472	5.375	425.6	398.0	373.2	366.5	17083	15729	14556	14232
PLR012	1.937	1.750	1.605	1.565	4.961	4.564	4.268	4.183	433.8	399.0	373.2	365.8	16932	15297	14031	13682
PLR013	3.220	2.979	2.856	2.823	6.657	6.229	6.030	5.971	466.5	436.5	422.6	418.5	22569	20877	20015	19783
PLR015	4.041	3.745	3.285	3.161	9.026	8.473	7.587	7.351	477.0	447.7	400.9	388.4	21354	19787	17359	16701
PLR016	3.610	3.325	3.120	2.996	7.421	6.969	6.651	6.46	305.8	287.2	274.1	266.2	14878	13704	12859	12346
PLR017	3.273	2.994	2.764	2.696	8.388	7.822	7.368	7.232	347.2	323.8	305.0	299.4	13550	12393	11441	11160
PLR019	3.817	3.540	3.228	3.134	9.662	9.122	8.486	8.304	334.0	315.4	293.4	287.1	13196	12239	11161	10836
PLR020	1.769	1.627	1.364	1.291	5.408	5.053	4.373	4.187	454.2	424.3	367.2	351.6	14854	13665	11451	10841
PLR022	1.031	0.963	0.819	0.781	3.065	2.891	2.518	2.421	654.9	617.9	538.3	517.4	22043	20588	17500	16701
PLR024	2.431	2.252	2.035	1.978	5.984	5.607	5.158	5.036	556.9	521.9	480.1	468.8	22625	20959	18944	18412
PLR025	1.869	1.743	1.415	1.324	5.528	5.222	4.408	4.184	455.1	429.9	362.9	344.5	15384	14352	11649	10904

PLR027	4.025	3.675	3.576	3.547	8.614	8.005	7.825	7.777	375.2	348.6	340.8	338.7	17531	16003	15572	15449
PLR028	3.541	3.178	3.104	3.083	7.418	6.805	6.696	6.659	344.7	316.2	311.1	309.4	16454	14765	14425	14323
PLR030	1.540	1.419	1.364	1.349	4.473	4.186	4.054	4.017	423.7	396.5	383.9	380.5	14582	13436	12915	12772
PLR031	5.958	5.459	5.066	4.957	12.142	11.298	10.595	10.409	422.2	392.9	368.4	361.9	20718	18980	17617	17237
PLR032	2.890	2.666	2.640	2.633	7.218	6.772	6.747	6.732	339.0	318.1	316.9	316.2	13577	12524	12403	12367
PLR033	1.423	1.323	1.200	1.167	4.016	3.775	3.494	3.415	506.2	475.8	440.4	430.5	17940	16672	15124	14711
PLR036	2.702	2.439	2.208	2.144	6.154	5.655	5.208	5.086	455.2	418.3	385.2	376.2	19986	18042	16327	15857
PLR037	2.758	2.459	2.218	2.155	6.277	5.699	5.210	5.084	596.8	541.8	495.3	483.3	26222	23379	21090	20489
PLR039	3.726	3.461	3.281	3.225	9.432	8.927	8.567	8.462	306.7	290.3	278.6	275.2	12117	11254	10669	10487
PLR041	9.604	9.183	8.428	8.164	19.39	18.78	17.71	17.35	261.9	253.7	239.2	234.3	12968	12399	11380	11023
PLR045	13.342	12.051	11.122	10.802	26.436	24.525	23.262	22.818	275.8	255.9	242.7	238.1	13919	12573	11604	11269
PLR046	6.109	5.668	5.474	5.412	12.964	12.265	11.927	11.831	293.9	278.1	270.4	268.2	13850	12851	12409	12269
PLR048	10.341	9.296	9.190	9.124	26.900	25.735	25.617	25.548	170.1	162.7	162.0	161.6	6539	5878	5811	5770
PLR049	2.991	2.743	2.408	2.284	7.547	7.116	6.536	6.333	258.9	244.1	224.2	217.2	10259	9410	8259	7835
PLR052	2.512	2.292	2.146	2.103	6.978	6.493	6.190	6.097	352.3	327.8	312.5	307.8	12680	11569	10834	10619
PLR053	2.702	2.493	2.438	2.420	7.926	7.475	7.336	7.299	297.5	280.6	275.4	274.0	10144	9358	9151	9086
PLR055	3.508	3.210	3.049	3.000	8.420	7.860	7.583	7.493	324.8	303.2	292.5	289.0	13532	12383	11761	11573
PLR058	1.921	1.736	1.664	1.643	5.407	4.994	4.825	4.778	373.9	345.3	333.6	330.4	13281	12005	11505	11361
PLR059	2.938	2.729	2.457	2.378	7.626	7.203	6.619	6.457	363.3	343.1	315.3	307.6	13993	13002	11705	11327
PLR060	7.009	6.636	5.673	5.363	14.994	14.377	12.837	12.346	308.3	295.6	263.9	253.8	14409	13643	11662	11024
PLR074	3.983	3.725	3.655	3.632	9.882	9.410	9.314	9.273	279.9	266.5	263.8	262.7	11280	10551	10353	10288
PLR075	3.402	3.112	3.096	3.092	7.339	6.819	6.776	6.768	445.9	414.3	411.7	411.2	20668	18907	18813	18787
PLR078	2.023	1.884	1.739	1.699	6.292	5.937	5.572	5.469	430.3	406.0	381.1	374.1	13835	12889	11892	11619
PLR081	2.937	2.645	2.342	2.256	6.805	6.249	5.673	5.51	409.2	375.7	341.1	331.3	17660	15903	14079	13563
PLR082	3.585	3.321	3.120	3.063	8.346	7.845	7.479	7.372	375.5	353.0	336.6	331.8	16134	14945	14041	13783
PLR084	2.613	2.432	2.230	2.176	6.149	5.786	5.396	5.288	494.3	465.1	433.7	425.0	21006	19544	17926	17493
PLR087	2.507	2.302	2.266	2.256	6.744	6.287	6.187	6.165	505.8	471.6	464.1	462.4	18804	17270	16998	16926
PLR088	2.671	2.516	2.439	2.416	7.828	7.475	7.294	7.243	335.7	320.6	312.8	310.6	11455	10788	10459	10362
PLR090	2.219	2.087	2.078	2.075	5.920	5.640	5.611	5.605	379.7	361.7	359.8	359.4	14231	13383	13326	13309
PLR091	2.263	2.152	1.593	1.448	5.779	5.536	4.286	3.958	655.6	628.0	486.2	448.9	25671	24410	18066	16421
PLR092	2.398	2.252	1.880	1.781	6.113	5.799	4.972	4.756	570.9	541.6	464.4	444.2	22399	21034	17554	16638
PLR093	1.300	1.217	1.078	1.041	3.957	3.741	3.382	3.286	581.9	550.2	497.5	483.4	19115	17895	15849	15314
PLR094	1.528	1.427	1.223	1.169	4.322	4.082	3.581	3.449	573.8	542.0	475.4	457.9	20281	18949	16236	15523
PLR095	0.960	0.908	0.633	0.562	3.226	3.080	2.257	2.043	672.5	642.0	470.5	425.8	20006	18932	13193	11704
PLR096	2.255	2.050	1.781	1.704	5.680	5.257	4.713	4.556	394.9	365.5	327.7	316.8	15682	14251	12382	11847
PLR097	1.366	1.272	0.968	0.889	4.239	3.991	3.167	2.95	610.1	574.4	455.8	424.6	19665	18302	13939	12796
PLR098	1.440	1.340	1.077	1.007	4.263	4.009	3.349	3.169	562.8	529.3	442.2	418.5	19020	17696	14218	13299
PLR099	4.459	4.247	2.832	2.411	9.403	9.031	6.532	5.811	429.7	412.7	298.5	265.5	20377	19405	12942	11017
PLR100	4.683	4.311	4.198	4.163	10.773	10.131	9.908	9.848	302.1	284.1	277.8	276.1	13130	12087	11771	11673
PLR101	5.002	4.699	4.251	4.098	10.765	10.296	9.600	9.371	272.9	261.0	243.3	237.5	12676	11910	10774	10385
PLR102	3.083	2.992	1.925	1.641	7.057	6.884	4.731	4.158	604.9	590.1	405.5	356.5	26423	25649	16500	14065
PLR103	1.027	1.006	0.661	0.575	3.684	3.618	2.508	2.223	935.2	918.1	636.5	564.0	26072	25529	16786	14594

PLR104	2.570	2.493	1.798	1.612	7.007	6.831	5.201	4.763	537.3	523.8	398.8	365.3	19707	19116	13788	12361
PLR105	2.520	2.483	1.555	1.315	6.580	6.495	4.362	3.8	703.5	694.5	466.4	406.3	26951	26553	16623	14062
PLR106	4.445	4.128	3.479	3.305	9.952	9.358	8.085	7.75	509.5	479.1	413.9	396.8	22754	21131	17813	16920
PLR107	1.589	1.541	1.035	0.897	5.288	5.157	3.696	3.303	532.3	519.1	372.0	332.4	15996	15510	10414	9033
PLR108	1.779	1.706	1.281	1.171	5.858	5.657	4.428	4.106	621.4	600.1	469.7	435.6	18869	18101	13593	12417
PLR109	2.958	2.804	2.210	2.035	7.858	7.530	6.264	5.895	378.5	362.7	301.7	283.9	14246	13506	10646	9801
PLR110	2.875	2.758	1.868	1.616	6.662	6.433	4.699	4.208	471.3	455.0	332.3	297.6	20331	19506	13208	11428
PLR111	1.649	1.605	1.002	0.833	5.102	4.988	3.399	2.957	498.5	487.4	332.1	288.9	16117	15684	9787	8135

4-7- Targets, Limits, and Warning Values at the Federal level

The process for proposing suitable targets, limits, no deterioration, and warning values at the federal level follows the same methodology applied at the regional level (Section 4-5). Results for federal states with increasing population are presented in Table 18, and the results for states with decreasing population are shown in Table 19. *DIS* values are presented in Appendix D.

Table 18 - Proposed targets, limits, no-deterioration, and warning values for Germany's states with increasing population

	WUP **(UPU/m²)**				***PBA*** **(%)**				***LUP*** **(m²/ (inh. or job))**				***WSPC*** **(UPU/ (inh. or job))**			
Federal State	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target
Baden-Württemberg	3.310	3.193	3.116	3.039	9.968	9.772	9.645	9.518	208.2	204.1	201.5	198.8	6914	6670	6509	6348
Bayern	3.197	3.103	3.079	3.055	7.981	7.810	7.767	7.724	282.3	276.3	274.7	273.2	11310	10978	10893	10809
Berlin	3.382	3.060	1.950	0.839	63.209	62.671	57.781	52.890	93.2	92.0	85.2	78.3	500	452	288	124
Bremen	13.999	13.655	13.065	12.474	40.906	40.577	39.974	39.370	155.7	154.5	152.2	149.9	5329	5198	4973	4748
Hamburg	6.395	5.901	4.325	2.749	48.443	47.801	45.031	42.260	111.1	109.7	103.3	96.9	1467	1354	992	630
Hessen	3.079	2.984	2.922	2.859	9.420	9.257	9.152	9.047	208.6	205.0	202.7	200.4	6819	6608	6470	6332
Nordrhein-Westfalen	5.742	5.740	5.738	5.736	14.502	14.499	14.497	14.494	193.8	193.7	193.7	193.7	7673	7670	7667	7665

Table 19 - Proposed targets, limits, no-deterioration, and warning values for Germany's states with decreasing population

	WUP **(UPU/m²)**				***PBA*** **(%)**				***LUP*** **(m²/ (inh. or job))**				***WSPC*** **(UPU/ (inh. or job))**			
Federal State	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target
Brandenburg	1.924	1.811	1.553	1.485	5.234	4.974	4.376	4.216	525.8	499.8	439.6	423.6	19334	18195	15608	14920

Mecklenburg-Vorpommern	1.428	1.327	1.043	0.967	4.231	3.977	3.253	3.059	546.9	514.1	420.5	395.4	18468	17153	13481	12504
Niedersachsen	3.484	3.178	3.118	3.101	7.916	7.364	7.257	7.226	342.4	318.6	314.0	312.6	15073	13749	13491	13415
Rheinland-Pfalz	3.586	3.344	3.301	3.288	9.082	8.608	8.524	8.499	322.1	305.3	302.3	301.4	12722	11862	11708	11662
Saarland	7.006	6.637	5.667	5.355	14.996	14.386	12.822	12.328	308.7	296.1	263.9	253.7	14419	13659	11663	11020
Sachsen	4.308	4.044	3.205	2.953	9.390	8.922	7.453	7.018	369.8	351.4	293.5	276.4	16968	15928	12624	11629
Sachsen-Anhalt	2.237	2.173	1.5	1.322	6.389	6.231	4.564	4.118	588.6	574.1	420.5	379.5	20620	20023	13818	12179
Schleswig-Holstein	3.525	3.191	3.185	3.178	8.065	7.469	7.459	7.446	323.4	299.5	299.1	298.6	14136	12797	12773	12744
Thüringen	2.246	2.168	1.484	1.293	6.312	6.128	4.512	4.061	471.1	457.3	336.7	303.1	16763	16177	11078	9649

4-8- Targets, Limits, and Warning Values at the Country level

The number of inhabitants and jobs at the national level in Germany increases until 2026 but will then show a steady decline. However, by 2050, the total number is still slightly bigger than the number observed in 2015. Determining whether scenario 5A or 5B (for setting the target) is more appropriate in this context is therefore challenging. To address this, an alternative approach was applied: considering Germany's mix of growing and shrinking regions, the estimated built-up areas by 2050 under scenarios 5A and 5B respectively, were summed across all regions, and the other components of *WUP* were calculated. For setting the other reference values (limit, no-deterioration, and warning value), the same methodology used at other levels of analysis was applied (Tab. 20).

Table 20 - Proposed target, limit, no-deterioration, and warning values for Germany

	WUP **(UPU/m²)**				***PBA*** **(%)**				***LUP*** **(m²/ (inh. or job))**				***WSPC*** **(UPU/ (inh. or job))**			
Federal State	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target	Warning	No deterioration	Limit	Target
Germany	3.484	3.348	3.137	2.925	8.607	8.366	8.104	7.842	260.5	253.2	245.3	237.4	10547	10134	9494	8854

5- Discussion

5-1- Urban Sprawl Trends from 1995 to 2015 in Germany's Planning Regions

Urban sprawl across almost all planning regions of Germany increased steadily between 1995 to 2015. The increase in urban sprawl in Germany is primarily explained by a considerable increase in the total amount of built-up areas, their high dispersion, and a notable rise in land uptake per inhabitant or job.

In general, the regions in the west of Germany experienced higher levels of *WUP* and showed more significant increases over the years. According to the Urban Sprawl in Europe joint EEA-FOEN report (2016), *WUP* values can be categorized into six groups, ranging from least to most sprawled. At the regional level (NUTS-2), these categories are as follows:

1. Values of < 1 UPU/m² indicate areas that are not sprawled;
2. Values of 1–2 UPU/m² indicate areas that are slightly sprawled;
3. Values of 2–4 UPU/m² indicate intermediate levels of sprawl;
4. Values of 4–6 UPU/m² indicate areas that are highly sprawled;
5. Values of 6–9 UPU/m² indicate very high levels of sprawl;
6. Values of > 9 UPU/m² indicate extremely high levels of sprawl.

As shown in Figures 71–73, most regions in the northeast and a few in the north, west, and south of Germany, were considered not sprawled (*WUP* < 1 UPU/m²) in 1995. These regions became more sprawled over time as the components of urban sprawl increased (*PBA, DIS, LUP*). By 2015, only two regions, PLR022 and PLR095, had *WUP* values below 1 UPU/m² (0.963 UPU/m² and 0.908 UPU/m², respectively). PLR022 (Landkreis Lüchow-Dannenberg) is the least populated region in Germany (66,285 inhabitants and jobs in 2015), and its landscape is characterized by riverside woodlands and a hilly countryside. PLR095 (Region Mecklenburgische Seenplatte), although not small in size, contains a significant number of lakes. Additionally, the level of *PBA* in this region increased slightly from 2.27% in 1995 to 3.11% in 2015.

In general, the west and north-west of Germany could be considered more sprawled compared to other parts. Many regions in these parts are more populated and are more urbanized.

The only exception in past *WUP* trends is PLR089 (Berlin). The *WUP* value in Berlin increased until 2005 but then began to decline. It was 2.095 UPU/m² in 1995, rose to 3.849 UPU/m² in 2005, and then decreased slightly to 3.06 UPU/m² by 2015. Interestingly, Berlin experienced a slight population decline between 1995 and 2005. The total number of inhabitants and jobs was 4,725,422 in 1995, which decreased to 4,542,643 by 2005 and then increased again to 4,977,288 by 2015. However, while the population was increasing, *WUP* began to decrease. Although *PBA* levels were constantly rising—from 47.98% in 1995 to 50.68% in 2005 and 52.91% by 2015—the rate of *PBA* increase was slower than the rate of population growth. This phenomenon highlights the importance of densification in reducing *WUP* values, even in the context of urban population growth.

In 1995, 11 regions had *WUP* values greater than 4 UPU/m² (10.09% of the total). By 2005, this number increased to 19 regions (17.43%), and by 2015, 28 regions exceeded this threshold (25.69%). These regions fall into the categories of highly, very highly, or extremely highly sprawled areas. This upward trend in increasing urban sprawl highlights the urgent need for stronger measures to limit this form of unplanned growth, as well as the necessity of exploring various alternatives for future urban development.

Behnisch et al. (2022a) studied the extent of urban sprawl across Germany's planning regions between 1990 and 2014. However, their analysis was based solely on the number of inhabitants (WUP_p), without accounting for the number of jobs. Office buildings occupy a substantial share of urban areas, particularly in large cities and economic hubs. As a result, neglecting job data tends to result in higher levels of *WUP*. This explains why regions such as Berlin and Hamburg had higher WUP_p values in their study (11.36 UPU/m² and 18.71 UPU/m² in 2014, respectively), than in my analysis, which includes both inhabitants and jobs, the *WUP* values for these regions are significantly lower (3.06 UPU/m² and 5.9 UPU/m² in 2015, respectively). Additional differences also arise due to the use of a different built-up area dataset. The dataset used for the built-up area in their study is the Global Human Settlement Layer (GHSL) at a spatial resolution of 38 meters.

Moreover, Behnisch et al. (2022b) explored global urban sprawl trends between 1990 and 2014. They again used GHSL dataset for this study. When comparing their WUP_p values for Germany with the *WUP* values calculated in this study, the results appear more aligned. This similarity may be attributed to the larger geographic scale, as larger scales often leads to less variation across values (EEA–FOEN, 2016). Nonetheless, the WUP_p value for Germany in 2014 reported by Behnisch et al. was 3.4949 UPU/m², whereas the *WUP* value in my study for 2015 (national level) is slightly lower, at 3.3481 UPU/m². Based on the comparisons above, the urban sprawl values presented in my study offer lower values and greater accuracy, as they incorporate the number of jobs in addition to inhabitants.

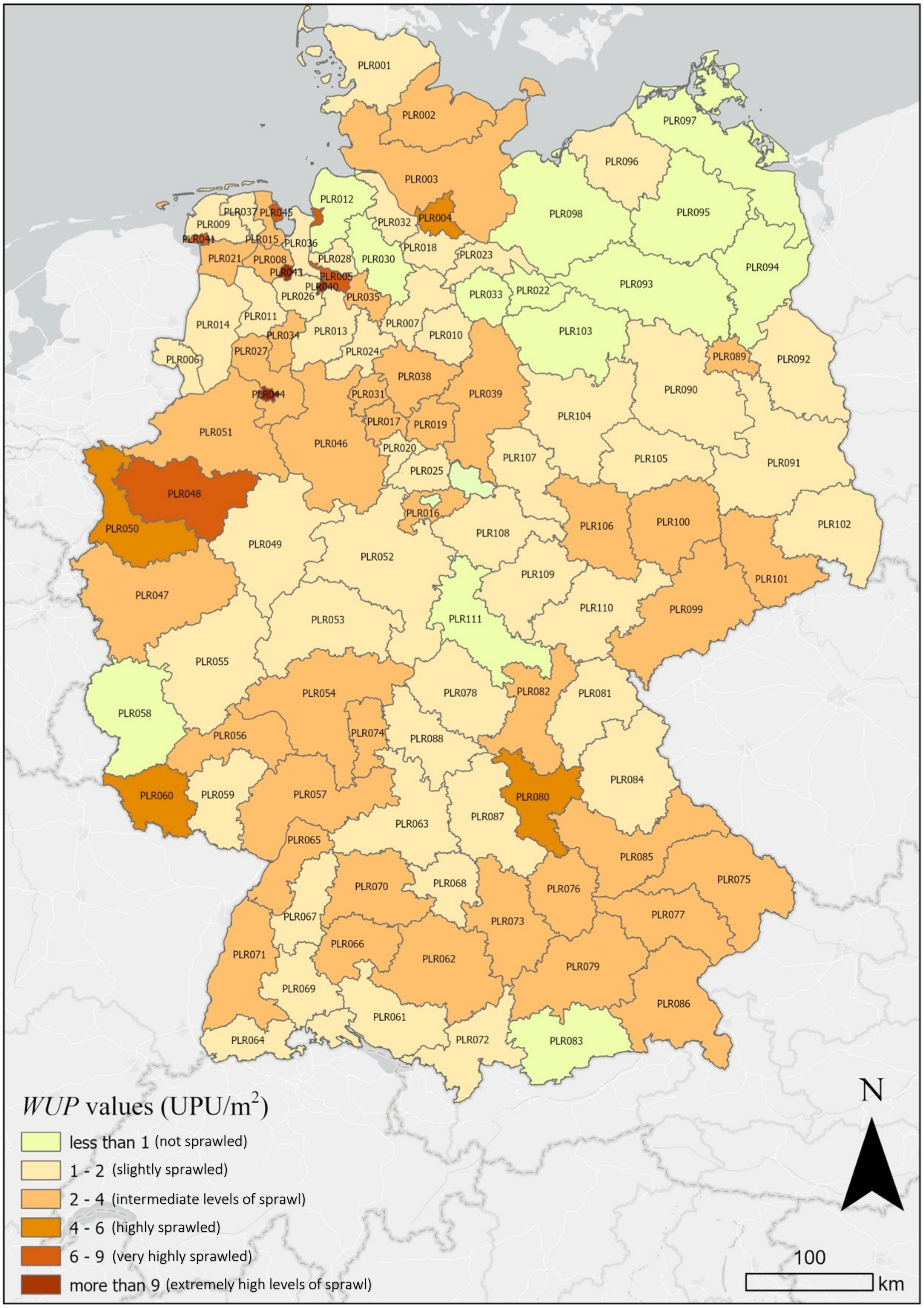

Figure 71 – Urban sprawl across planning regions of Germany in 1995

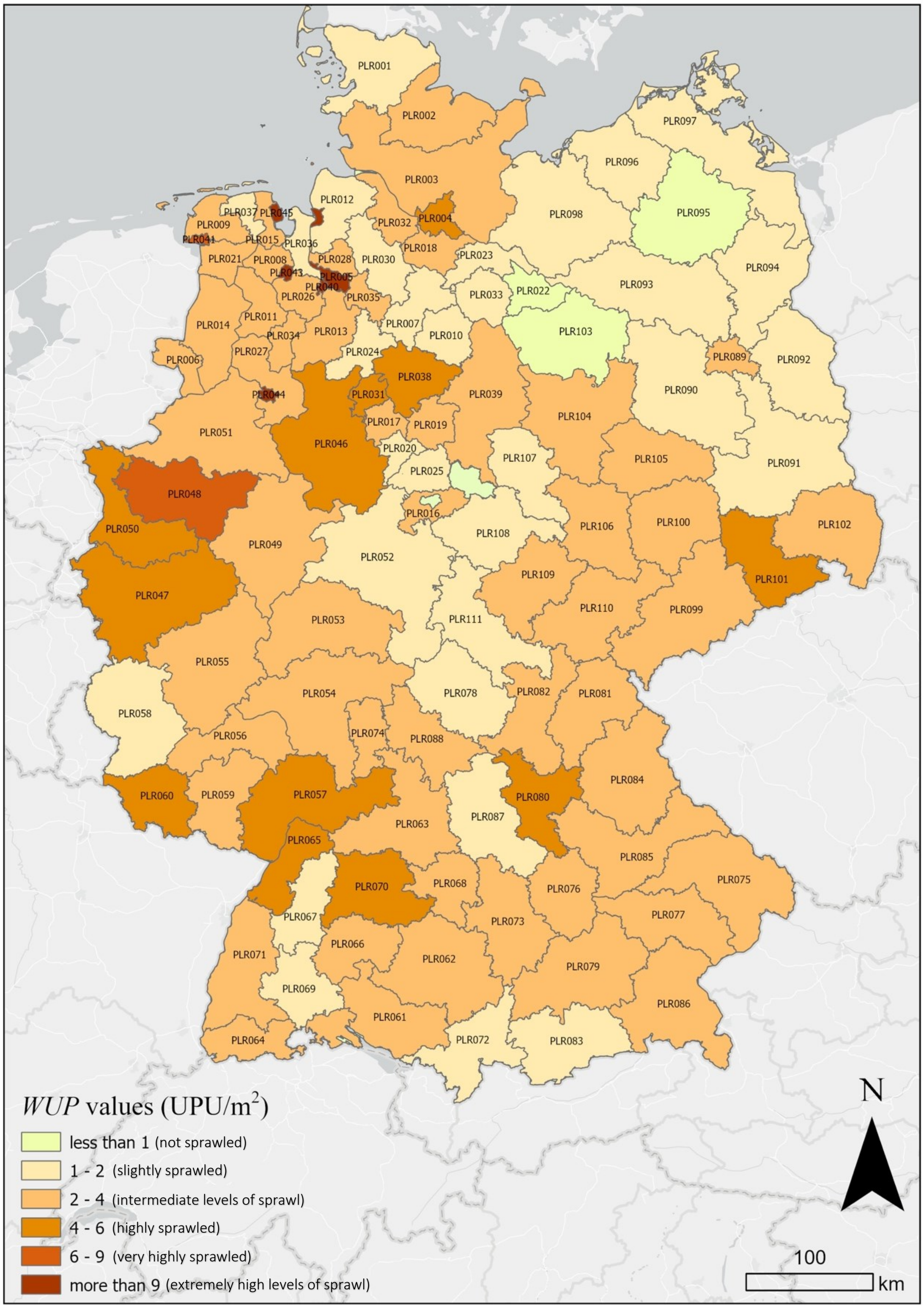

Figure 72 - Urban sprawl across planning regions of Germany in 2005

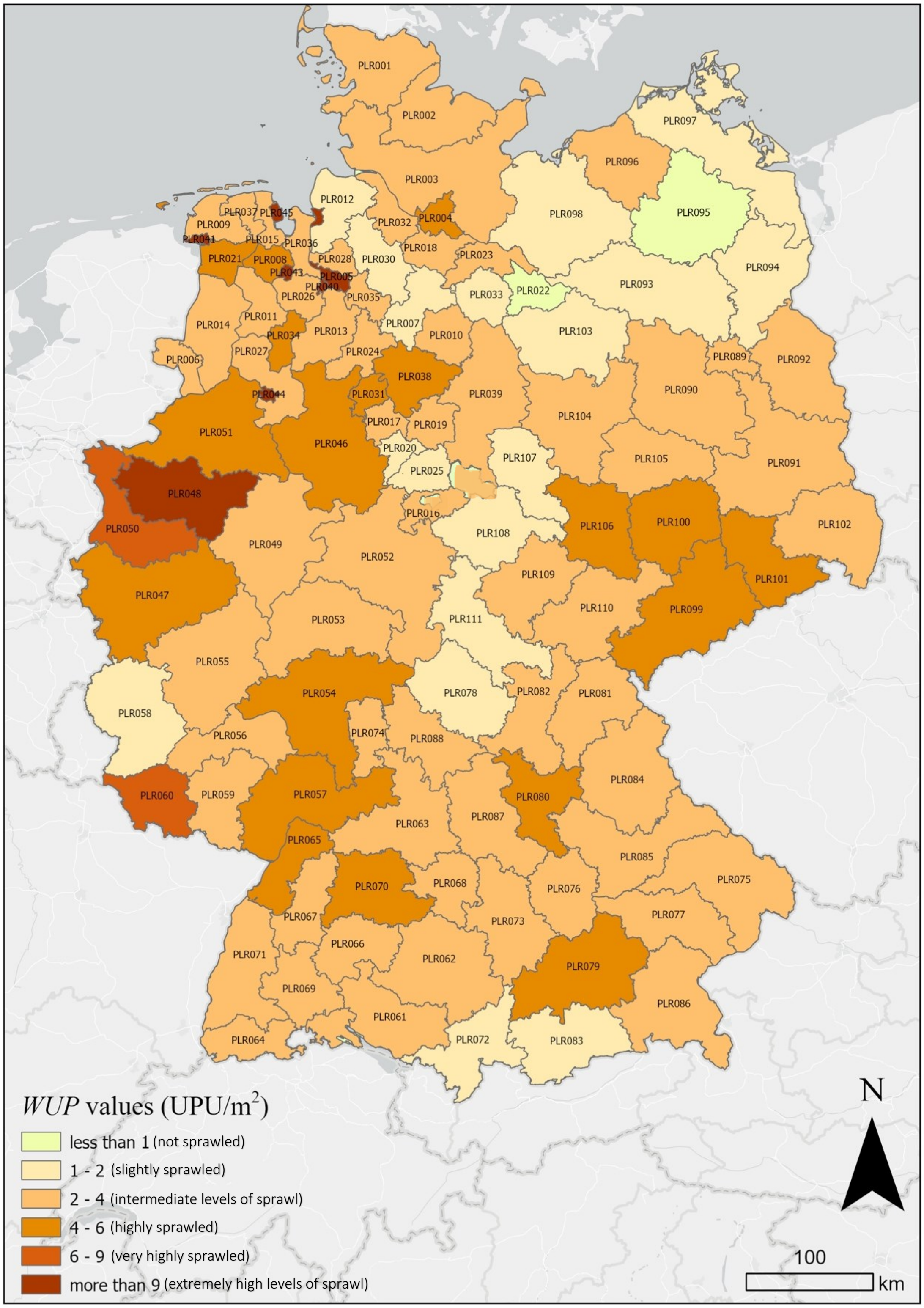

Figure 73 - Urban sprawl across planning regions of Germany in 2015

5-2- Urban Sprawl Trends from 1995 to 2015 in Germany's Federal States

Just like in Germany's planning regions, urban sprawl increased steadily across nearly all federal states between 1995 and 2015. Figures 74–76 illustrate the spatial distribution of urban sprawl levels across federal states at three points in time, each a decade apart: 1995, 2005, and 2015.

The EEA–FOEN urban sprawl report (2016) categorized *WUP* values into six groups, ranging from least to most sprawled, for NUTS-0 (country) and NUTS-2 (regional) levels. However, it did not provide a specific classification for the NUTS-1 level, which includes states or macro-regions with populations between 3 million and 7 million. Germany's federal states fall into this category.

The range of *WUP* values at the NUTS-1 level is less diverse than at the NUTS-2 level. Additionally, *WUP* values that would be considered high at the level of federal states are generally lower than those at the level of planning regions (EEA–FOEN, 2016). At the same time, federal states cannot be treated as countries. Therefore, for the purpose of this analysis, a classification system falling between the NUTS-0 and NUTS-2 categories was used. These categories are as follows:

1- Values of < 0.83 UPU/m² indicate areas that are not sprawled;

2- Values of 0.83–1.7 UPU/m² indicate areas that are slightly sprawled;

3- Values of 1.7–3.2 UPU/m² indicate intermediate levels of sprawl;

4- Values of 3.2–4.7 UPU/m² indicate areas that are highly sprawled;

5- Values of 4.7–6.7 UPU/m² indicate very high levels of sprawl;

6- Values of > 6.7 UPU/m² indicate extremely high levels of sprawl.

The states in the west of Germany were more sprawled compared to other states (Figs. 72-74). Bremen, Nordrhine-Westfalen, and Saarland were among the highly sprawled areas in 1995, which transitioned to very or extremely high levels of sprawl over the following 20 years. Mecklenburg-Vorpommern was the only state in good condition in 1995 but became slightly sprawled by 2015. Berlin's situation was discussed in Section 5.1 as the only state to show a reduction in the level of sprawl. By 2015, six states had reached high to extremely high levels of urban sprawl.

Another important topic that should be discussed is the impact of population and *PBA* on *WUP*. One key question is: Which had a greater effect on the level of urban sprawl between 1995 and 2015, population or *PBA*? In other words, while both parameters influence urban sprawl, can increases in *WUP* be equally justified by population growth and *PBA* expansion? And can someone claim that urban sprawl simply is the "natural" result of population growth?

Figure 76 shows the relative changes in *WUP*, *PBA*, and the number of inhabitants and jobs between 1995 and 2015 across Germany's federal states. As illustrated, *WUP* consistently increased alongside *PBA*, but this pattern does not hold for population change. In most federal states, the built-up area increased much more than the number of inhabitants and jobs. In five federal states, population even declined over the years, yet *WUP* rose due to increased built-up areas, more dispersed development, and higher land uptake per inhabitant or job. In the national level, an important observation is that between 1995 and 2015, the relative increase in built-up area (+ 31.11%) was more than four times greater than the growth in the number of inhabitants and jobs, which increased by only 7.2%. The increase in *WUP* was even more substantial, rising by 51.67%, which is 7.2 times larger than the relative population and employment growth (Fig. 78). *WSPC* also increased sharply (+41.48%), indicating how much urban sprawl is generated, on average, by each job or resident within the reporting unit. This difference highlights a significant transformation in Germany's landscape, where land consumption has grown substantially despite a relatively modest population increase.

In fact, there is this conflict in shrinking regions: on one hand, the population is declining, on the other, one of the most common growth-oriented "solutions" to urban shrinkage is housing construction (Fernandez & Hartt, 2022). The policymakers have been deeply concerned with addressing urban shrinkage. Regions in Germany experiencing slight population declines appear to be attempting to attract new residents through extensive residential development. But this expansion is coming at the cost of agricultural land, and there is no corresponding growth in commercial land use (Meyer et al., 2021). This highlights the urgent need for a more sustainable and balanced perspective on urban development such as densification by reducing built-up area and increasing green spaces in urban areas.

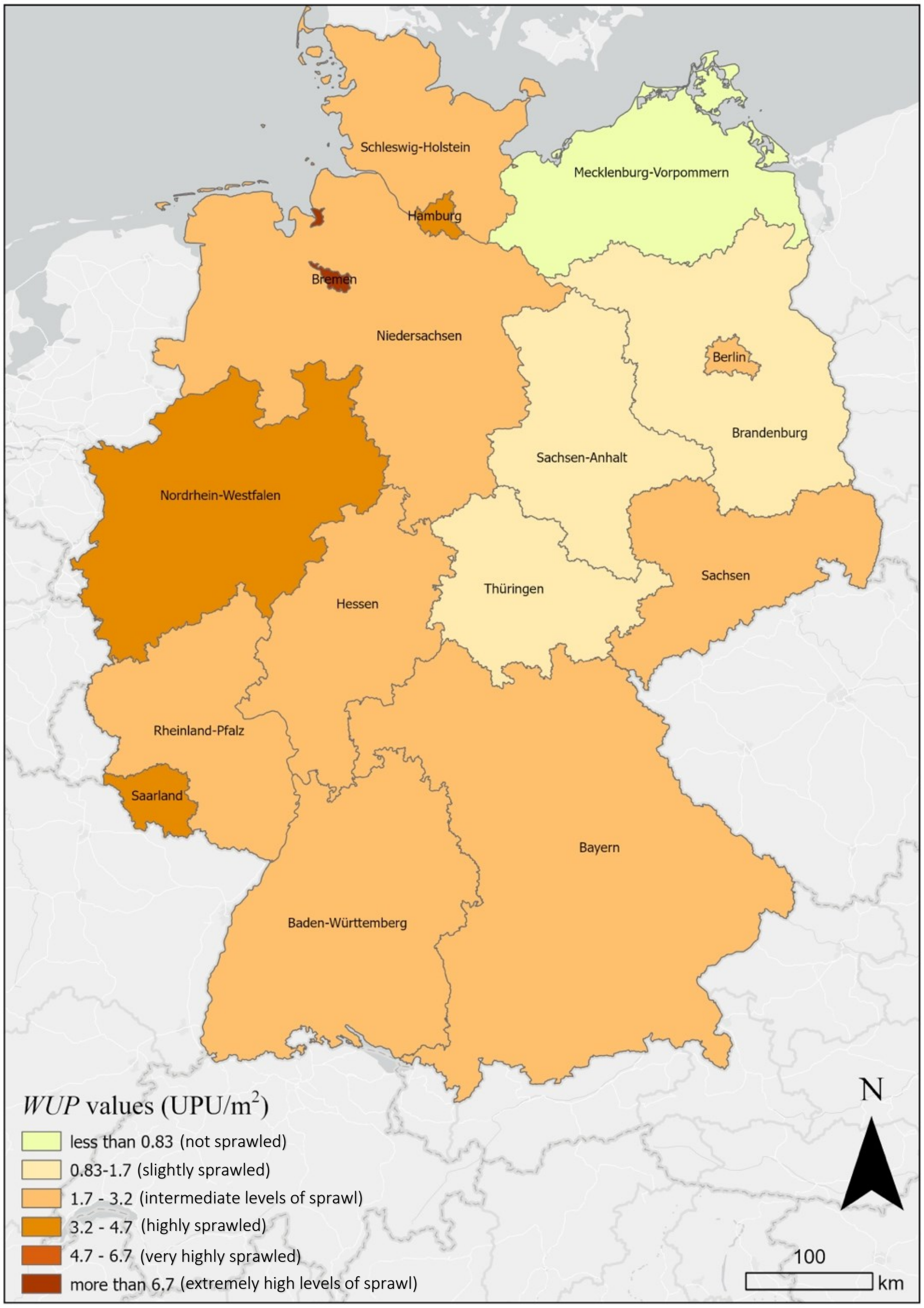

Figure 74 - Urban sprawl across federal states of Germany in 1995

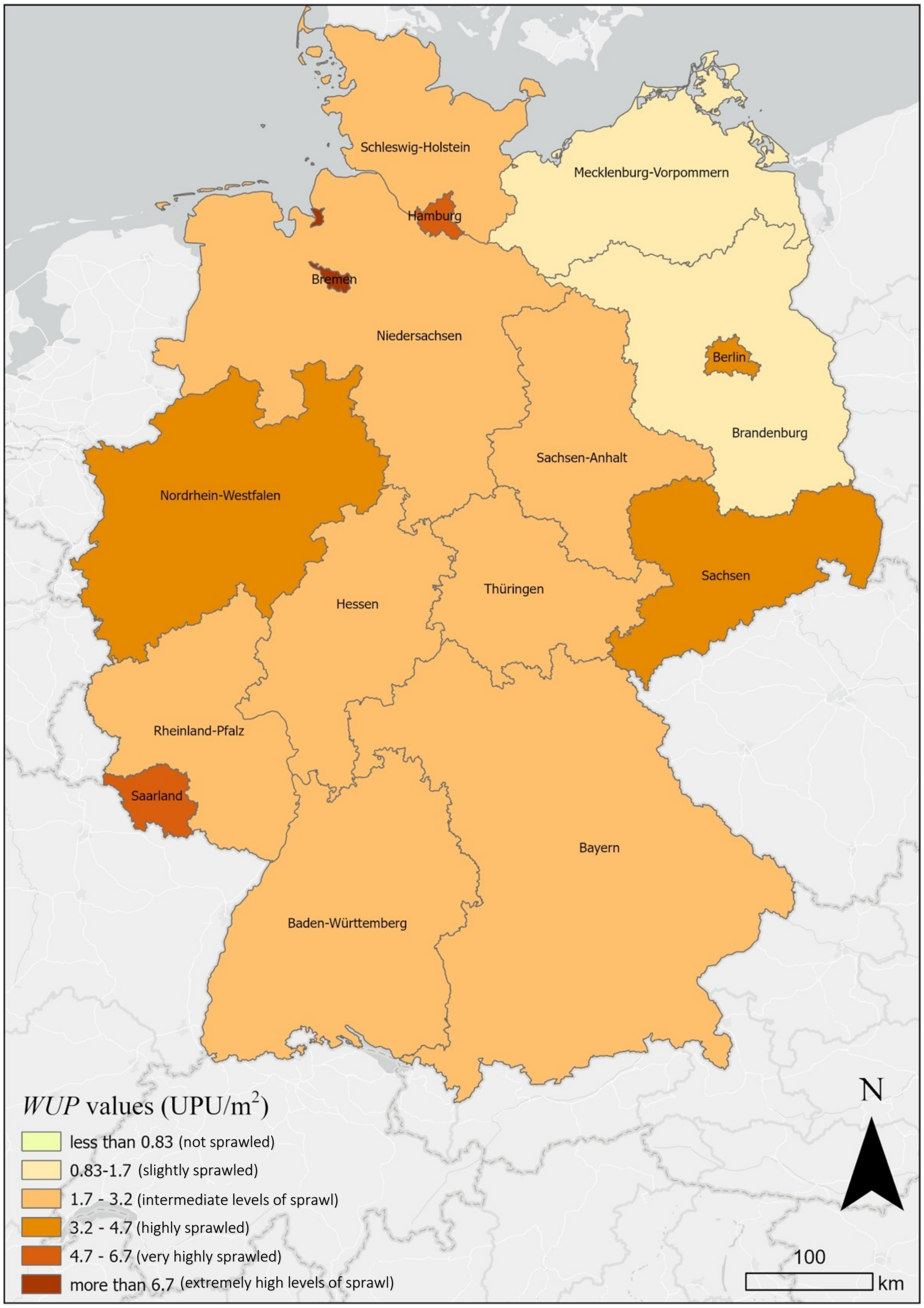

Figure 75 - Urban sprawl across federal states of Germany in 2005

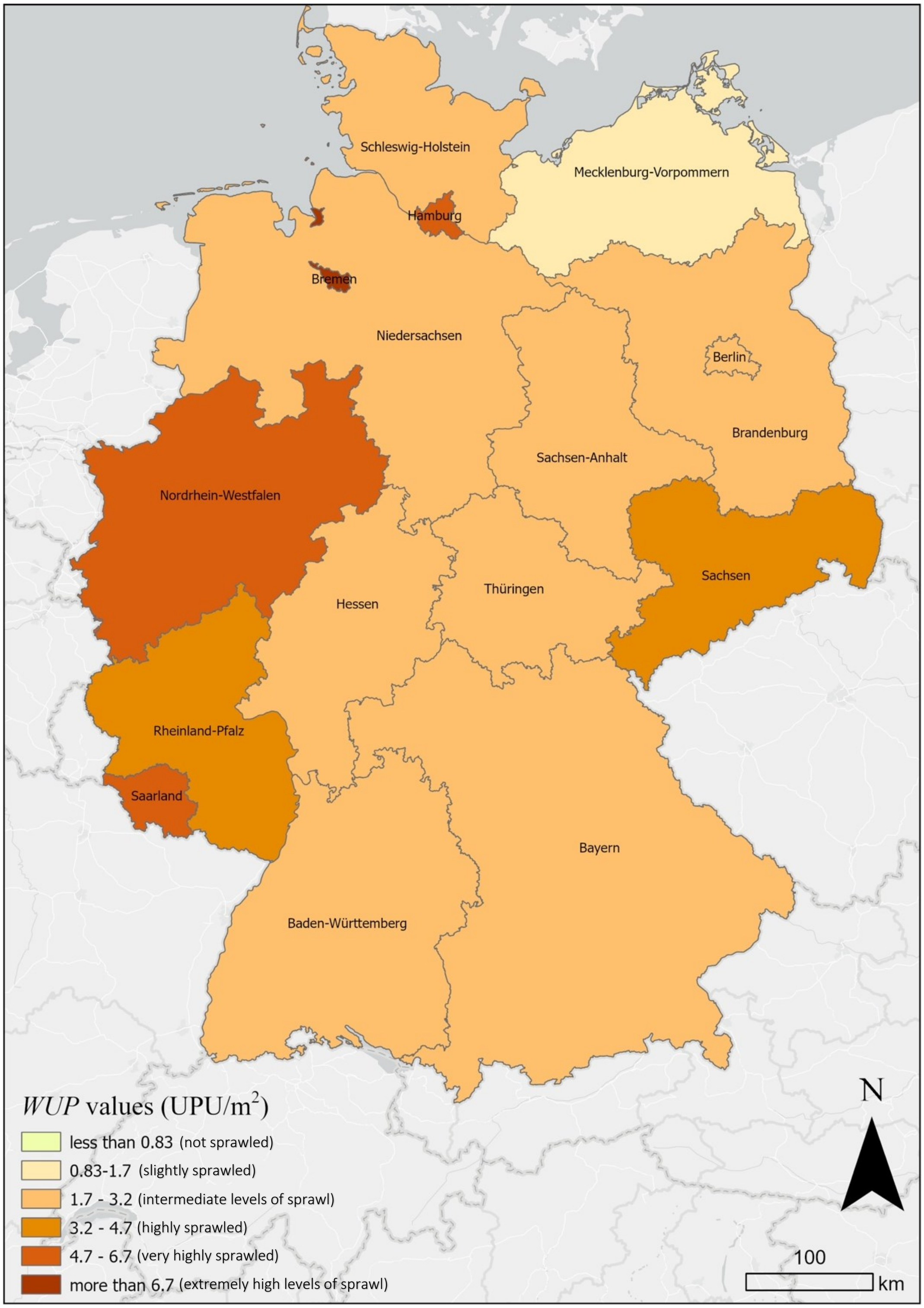

Figure 76 - Urban sprawl across federal states of Germany in 2015

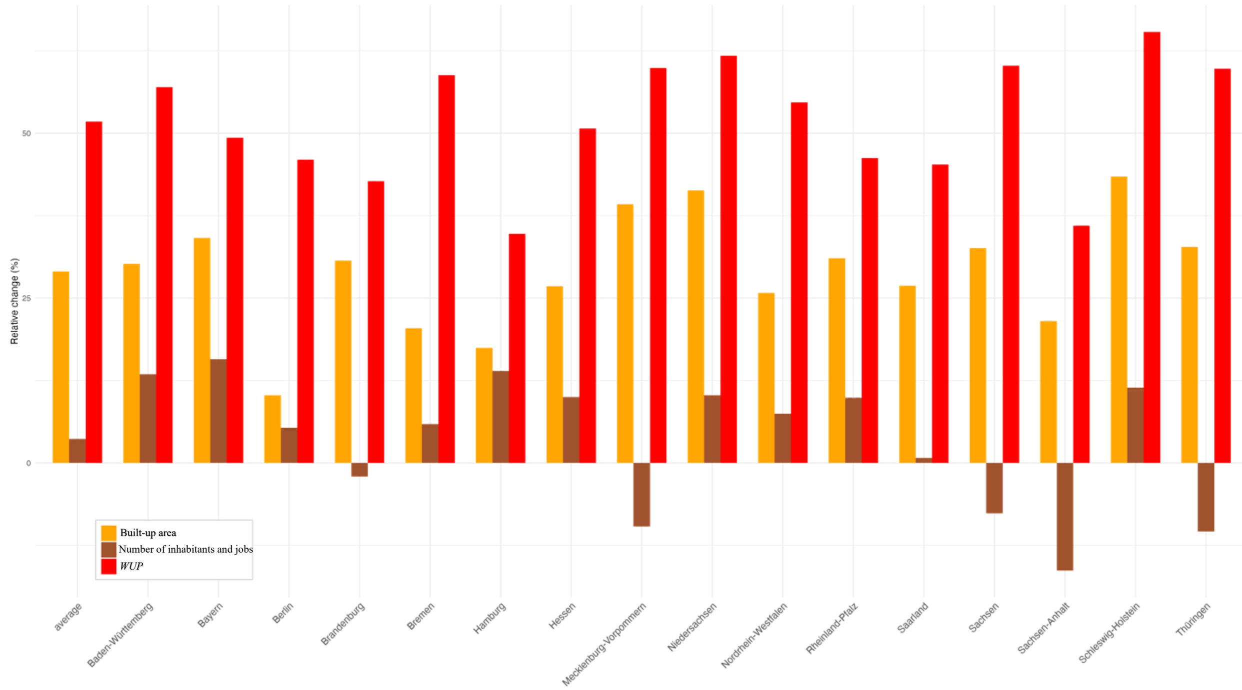

Figure 77 – Relative changes in WUP, PBA, and number of inhabitants and jobs between 1995 and 2015 across the 16 federal states of Germany

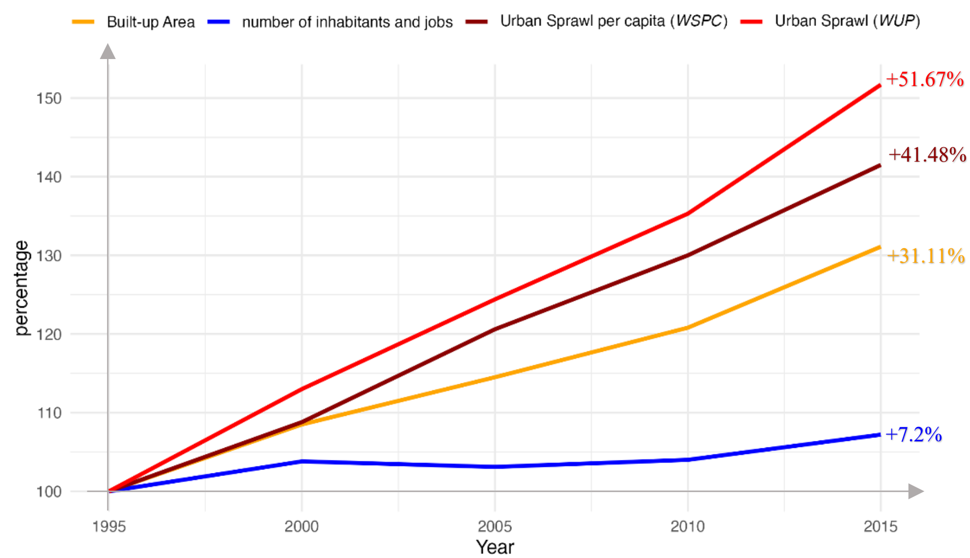

Figure 78 - Relative changes in WUP, WSPC, built-up area, and the number of inhabitants and jobs between 1995 and 2015 relative to the value of 1995 (corresponding to 100%)

5-3- Sustainability Analysis of Future Scenarios of Germany

Currently, there are few established frameworks for evaluating planning outcomes. Hersperger et al. (2017) proposed a reference framework for defining quantitative target values, aiming to assess whether planning objectives are being met based on various indicators. Schwick et al. (2018)

introduced six future scenarios for urban sprawl in Switzerland and defined reference values based on the more sustainable scenarios. In my thesis, I adopted a similar approach and applied it to Germany's planning regions and federal states.

Determining which scenarios are sustainable at an absolute level is challenging due to the complexity of the case study. Each planning region has its own unique characteristics. For instance, it is not feasible to categorize PLR089 (Berlin) and PLR111 (Südwestthüringen) together because of their significant differences in population, density, size, and landscape. However, relative comparisons are possible, as higher levels of urban sprawl indicate less sustainable situations. The following results can be summarized:

1- In scenario 1 (BAU), across all regions and states, all metrics of urban sprawl increased strongly by 2050, with the *WUP* value rising steadily by 45% nationwide between 2015 and 2050. This indicates that urban sprawl increased at a much faster rate than the growth in the number of inhabitants and jobs. As a result, the land conversion by built-up areas and the level of urban sprawl departs further from the goal of sustainability (Schwick et al., 2018). The increase in *PBA* implies the loss of land, often valuable agricultural land. From a biodiversity perspective, large green areas outside the city are more valuable than numerous small green spots scattered within the urban area (Skovbro, 2002). Therefore, the BAU scenario poses a serious threat to biodiversity.

2- Scenarios 2 (constant *LUP*) and 3 (*WUP* mirrors population and employment trends) exhibit varying levels of urban sprawl depending on regional characteristics. In regions with increasing populations, urban sprawl, *PBA*, and *DIS* would increase as well. The *WUP* rose on average by 7% and 6.34% in growing regions under scenarios 2 and 3, respectively, meaning urban sprawl increased at a similar (or slightly faster) rate than the growth in population and employment. Conversely, in shrinking regions, *WUP* decreased by 12.31% and 11.14% in scenarios 2 and 3, respectively, indicating a slight reduction in *PBA* and *DIS*.

3- Scenario 4 (constant urban sprawl) represents the no-deterioration zone. In this scenario, the total urban area increased in growing regions and decreased in shrinking areas. Therefore, in growing regions, this scenario is more sustainable than scenarios 1, 2, and 3, while in shrinking regions, scenarios 2 and 3 perform better than scenario 4. While scenario

4 can be considered a step in the right direction, it is only conditionally sustainable, and further efforts are needed.

4- Scenarios 5A and 5B (Densification) outline a quantitative pathway toward more compact development. In both scenarios, *WUP* decreased significantly. In scenario 5A (constant *PBA*), *WUP* dropped by 13% on average, while scenario 5B (−0.9 percentage points reduction in *PBA* on average) saw a 15.7% reduction. Scenario 5A proved most effective in regions with significant population growth, accommodating larger populations within the existing built-up areas through densification. Although a stricter scenario is not proposed to these slower-growing regions in this study, doing so and engaging in further discussion around it could contribute to much more sustainable urban areas.

Figures 79 and 80 illustrate the spatial distribution of urban sprawl across planning regions and federal states for each scenario in 2050. Although scenarios 2 and 3 show different values of urban sprawl, the values fall within the same classification ranges, which is why the maps for these two scenarios are identical.

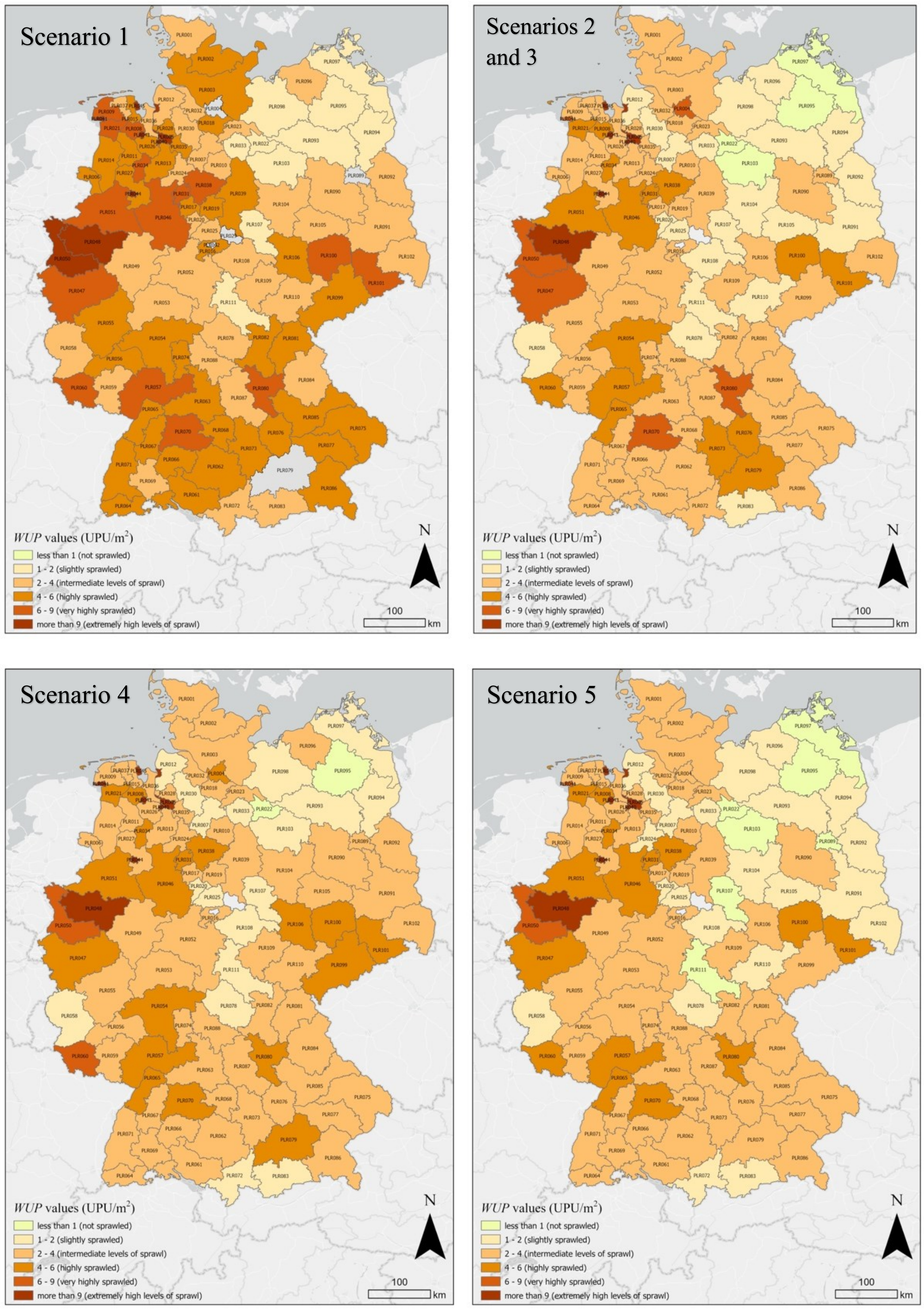

Figure 79 - Urban sprawl across planning regions of Germany by 2050 in scenarios 1 to 5

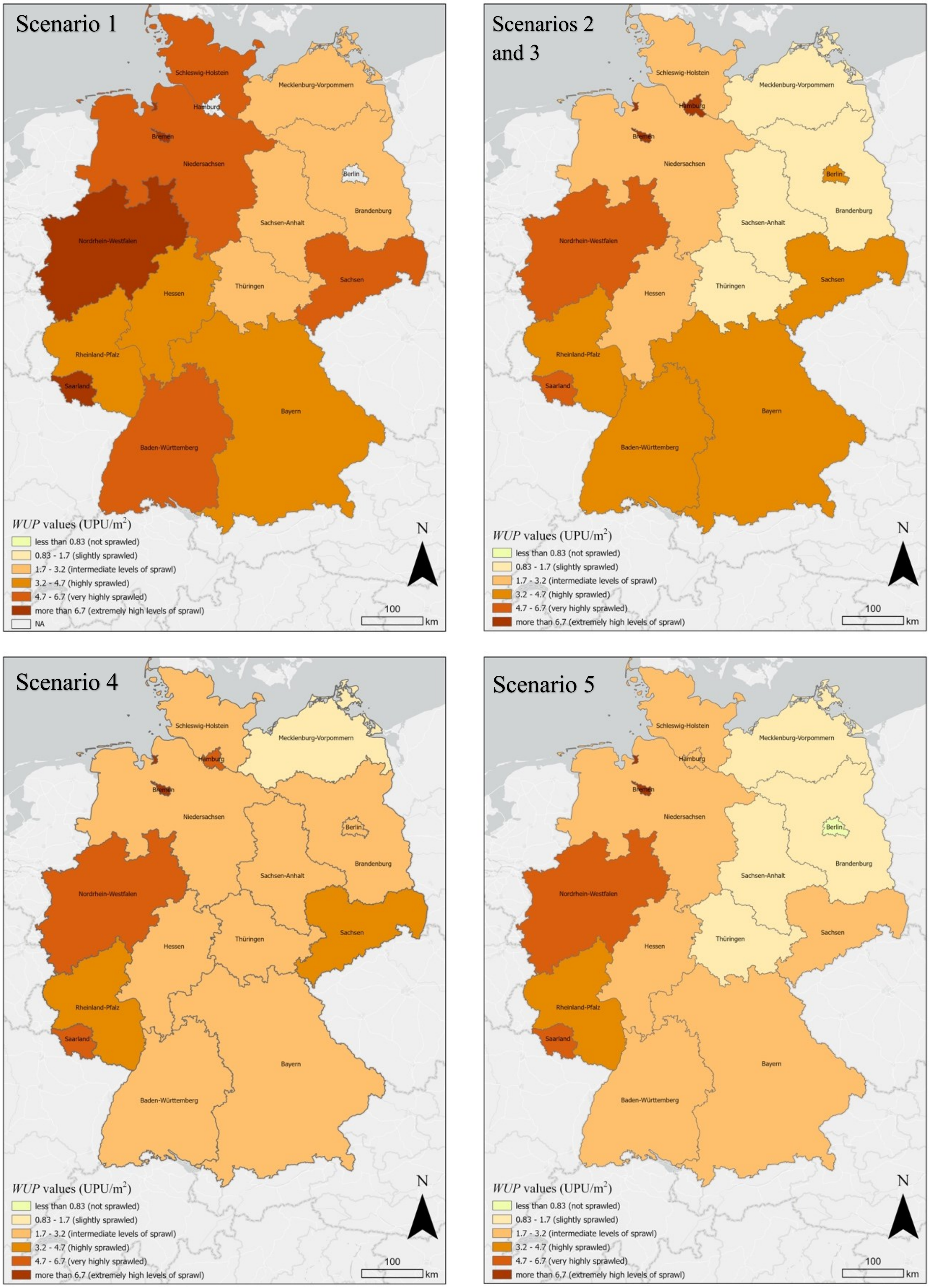

Figure 80 - Urban sprawl across federal states of Germany by 2050 in scenarios 1 to 5

While it may be impossible to assess in detail how sustainable each scenario is, due to the somewhat vague and context-based definition of sustainability, it is still feasible to identify the more sustainable ones based on the known outcomes of past unsustainable developments. This leads to an important question: Is urban densification environmentally sustainable, and why or why not?

Densification practices support the broader sustainability objective of reducing soil consumption, thus preserving rural landscapes and natural resources (Fatone et al., 2012). According to a study by Brenner et al. (2024) about Vienna, Austria, between 1984 and 2018, low-density regions tend to be less sustainable, as they require more energy and materials to support essential services such as housing, workplaces, and mobility. In contrast, the integration of densification strategies with the long-term preservation of Vienna's greenbelt effectively curbed urban expansion.

In another study by Næss et al. (2020), the outcomes of densification on the sustainability of Oslo were examined. Their results showed that, partly due to densification policies, the use of personal cars decreased, while the number of trips made by public transit increased by 35% between 2000 and 2012. Moreover, densification significantly reduced the loss of natural areas and farmland compared to the scenario in which the sprawling urban development patterns from before the mid-1980s had continued. However, urban densification in Oslo has not been without drawbacks. It negatively affected intra-urban vegetation and ecosystems. For example, between 1999 and 2004, there was a 5% reduction in open-access green areas.

These results underscore the importance of green space preservation in sustainability discussions. One suggestion to prevent this reduction in green spaces is large-scale urban reforestation. This specifically could benefit the shrinking regions that have (or will have) plenty of vacant areas. Sacramento is an example that implemented tree-planting programs and achieved measurable environmental and economic benefits such as energy savings and reductions in CO_2 levels (Hollander et al., 2009). Also, in "Emscher Park" in western Germany and the lesser-known project "Fuerst Pueckler Land" in eastern Germany, old industrial sites were converted into landscape parks and cultural attractions. The ultimate goal in this study's final scenario is that the reduced built-up areas (-13.9% on average), including vacant properties, brownfields, and outdoor parking spaces, be restored by various forms of urban green space, based on the specific needs of each region.

In general, from the perspective of a regional planner, densification serves as an essential tool for preserving valuable agricultural land and minimizing traffic volumes and make a model shift to public transport more feasible (Jehling et al., 2020). As one of the core objectives of Germany's land-use policy, densification is rooted in the broader discourse about sustainable development. It is regarded as a key measure to curb urban expansion and mitigate its negative environmental impacts (Bundesregierung, 2002). Notably, adjustments to the Federal Building Code in 2004 and 2007 introduced specific targets and legal provisions to promote densification through the redevelopment of existing urban areas (Jehling et al., 2020). Moreover, among the Sustainable Development Goals (SDGs), Goal 11 emphasizes the importance of "making cities inclusive, safe, resilient, and sustainable." Within this goal, Target 11.3 promotes sustainable urban planning and management. Specifically, Indicator 11.3.1, defined as the ratio of land consumption rate to population growth rate, serves as a key metric for assessing the balance between urban expansion and demographic change (Li et al., 2020; Ghazaryan et al., 2021). In 2015, the ratio of land consumption rate to population and job growth rate (between 1995-2015) was 4.33. By taking no sustainable actions (such as scenario 1), this ratio is projected to increase significantly to 9.2 (between 1995 and 2050), while by applying scenario 5 in Germany, this ratio is projected to decrease to 3.06 (between 1995 and 2050, or 2.37 between 2021 and 2050). The closer this ratio approaches 1, the more sustainable the urban environment becomes. However, achieving significantly lower values may be overly idealistic and somewhat unrealistic.

In more compact regions, the demand for roads and private car ownership is lower, which reduces CO_2 emissions and overall energy consumption (OECD, 2020). In Germany, energy use can be linked to dispersed built-up areas, too, as buildings currently account for approximately 30% of the country's greenhouse gas emissions in both direct and indirect ways. Additionally, the transport sector accounts for around 18% of national greenhouse gas emissions (BMUB, 2016).

As a final result, we can conclude that the proposed approach aligns with the European Union's "no net land take" objective and supports Germany's national target of reducing land consumption to less than 30 hectares per day by 2030. Based on all the arguments presented above, it is evident that scenario 5 (A and B) represents the most sustainable pathway, while scenario 1 (BAU) is the opposite of sustainable development. Furthermore, in shrinking regions, all the mentioned scenarios (as long as we do not continue the current path as in scenario 1) will result in lower level of sprawl as shown in each scenario with details, with scenario 5B as the most sustainable.

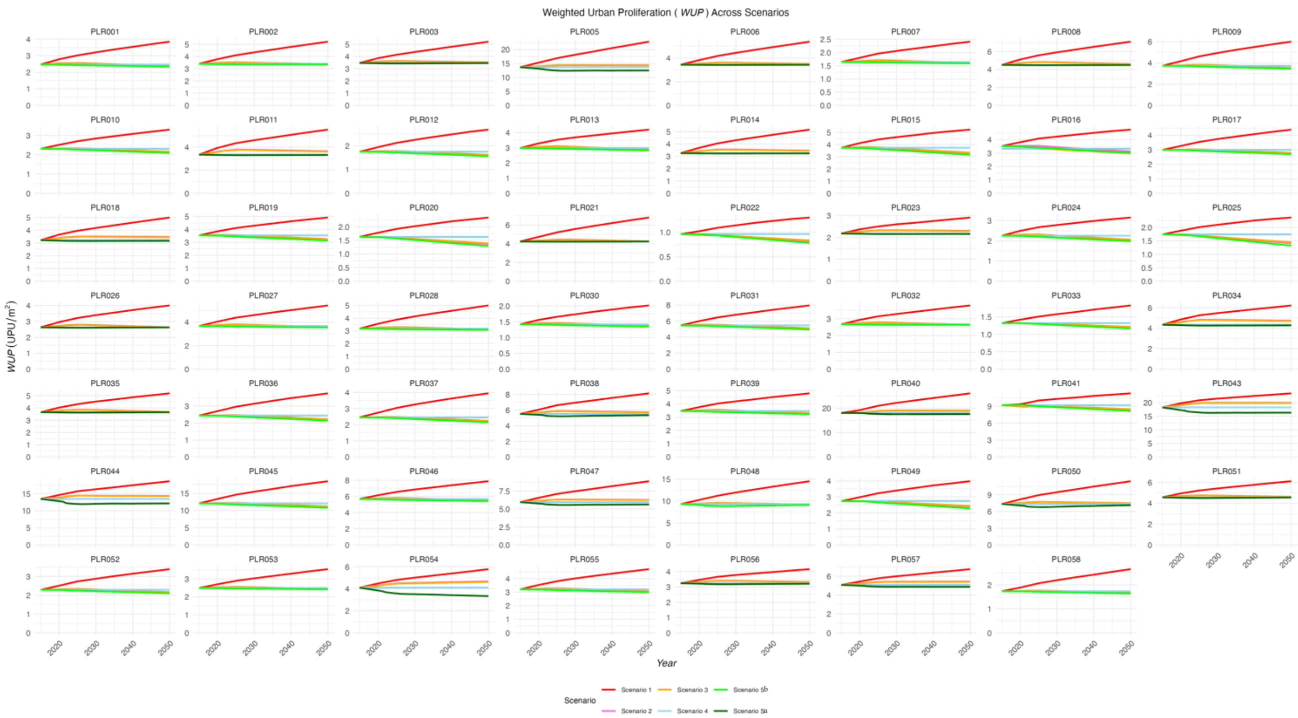

Figure 81 – WUP between 2015 and 2050 in Scenarios 1-5 (in PLR001-PLR058)

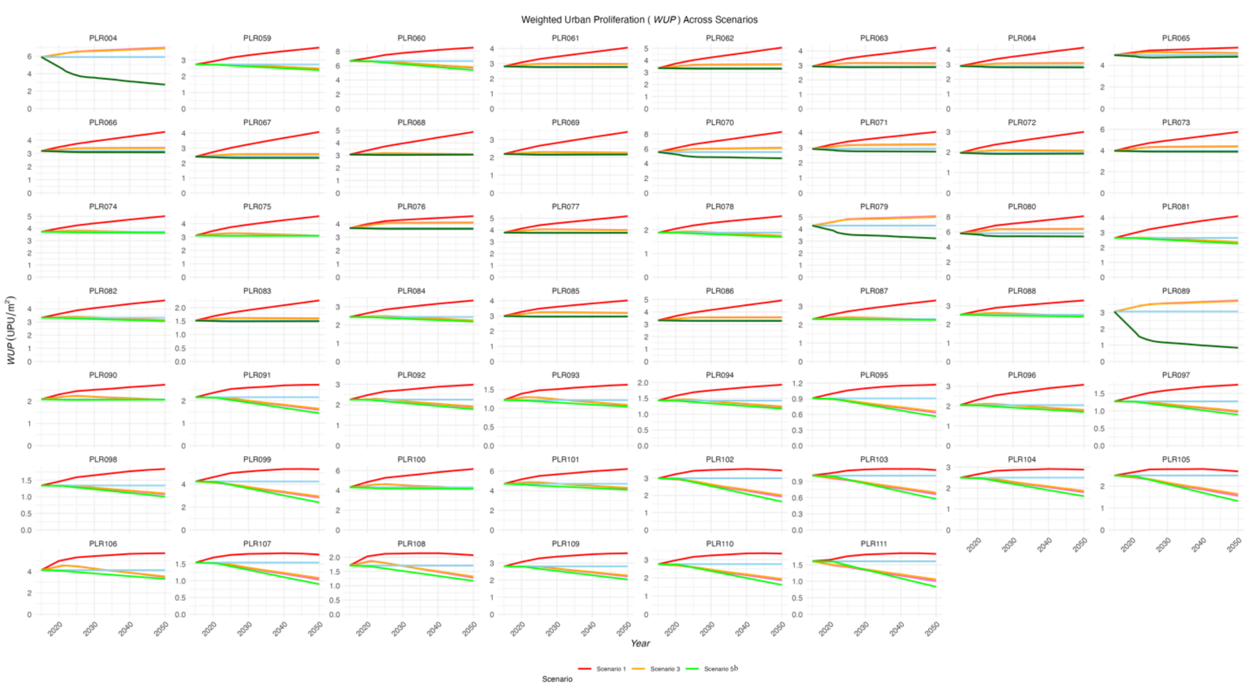

Figure 82 - WUP between 2015 and 2050 in Scenarios 1-5 (in PLR059-PLR111)

Figure 83 - WUP between 2015 and 2050 in Scenarios 1-5 in Germany's federal states

5-4- Targets and Limits to Urban Sprawl in Germany

When one of the components of *WUP* shows a higher value than its corresponding limit, this signals a potential risk of the *WUP* value soon surpassing its limit as well. The proposed targets, limits, and warning values for Germany's planning regions and federal states are directly tied to population trends, as the number of inhabitants and jobs significantly influences the extent of built-up areas and *LUP* and accordingly, urban sprawl. These proposed values are specifically based on the future scenarios of Germany. A uniform approach to defining targets and limits to urban sprawl across Germany's planning regions and federal states is not feasible as scenarios 2 and 3 produced differing outcomes depending on whether a region experienced population growth or decline. Therefore, reference values should be determined based on population trends. Based on the trends in the numbers of inhabitants or jobs, the key findings are as follows:

1 – For regions and states with increasing population, an approach similar to Schwick et al. (2018) was followed. This approach was also adopted in Mosharafian's work for Montreal (2023). However, in my study, the target value is set stricter (target value = Scenario 5A). This decision was made based on several reasons: The targets proposed here are not legally binding; rather, they should represent an ideal path toward a sustainable future. Even in regions with population growth, the increase is relatively modest. The average percentage increase in the number of inhabitants and jobs across planning regions between 2015 and 2050 is 6.34%.

Moreover, Germany is a country with ambitious sustainability goals. For example, it has a target to limiting land consumption to less than 30 hectares per day by 2030 (Germany's Integrated

Environmental Programme 2030, 2016). In 2023, Germany's total land take was approximately 53 hectares per day based on one-year differences. This total comprises 2 ha/d for transportation infrastructure (roads, driveways, railways, airports), 17 ha/d for sports and recreational areas (including parks and cemeteries), and 34 ha/d for housing, industrial, commercial, and public facilities (Federal environmental office, 2023). When compared with WSFevolution-based built-up area data, the category most closely aligned with built-up land corresponds to the housing, industry, and public facilities section, representing roughly 64% of total land take in 2023, while transportation accounts for only 3.8%. Thus, when translated to Germany's sustainability goal of limiting land take to 30 ha per day by 2030, this proportion equals to about 19.2 hectares per day of built-up area.

Therefore, setting a target of no further increase in *PBA* in a highly urbanized country moving towards sustainability is not unrealistic. Scenario 1 is far from this target, whereas under Scenario 5 the land consumption per day even becomes negative. Scenario 1 with 61.04 hectares per day land consumption, stays far from the 19.2 hectares per day target which is 3.18 times higher. Table 21 presents the land consumption under each scenario.

Table 21 – Land consumption (hectares per day) under each scenario in Germany

Scenario	Hectares per day (1995-2050)	Hectares per day (2021-2050)
Scenario 1	78.26	61.04
Scenario 2	32.19	-12.82
Scenario 3	32.51	-11.72
Scenario 4	36.16	-0.59
Scenario 5	26.03	-16.93

Applying densification (constant built-up area) in the context of substantial population growth, as seen in Hamburg with a predicted 16.6% increase in the number of inhabitants and jobs between 1995 and 2050, has a significant impact on the *WUP* level. In such cases, limited land resources must be shared by a growing number of people. This insight reflects the fact that accommodating higher population growth without further urban sprawl requires a focus on densification. Consequently, a lower *LUP* value must be achieved.

2 – In regions or states where the number of inhabitants and jobs remains relatively stable, such as Bayern or NordRhine-Westfalen, the overall approach for proposing reference values aligns with the approach used for regions experiencing population growth. However, in these areas, all four reference values are relatively close to one another (Figs. 85-87). Since population dynamics remain largely unchanged, there is little justification for additional expansion of built-up areas, and if any additional development occurs, this expansion should not deviate significantly from the status quo. For example, in Bayern, the current *WUP* level is 3.103 UPU/m², which serves as the no deterioration benchmark. The limit is set slightly lower at 3.079 UPU/m², the target is 3.055 UPU/m², and the warning threshold is 3.197 UPU/m². In other words, any increase in *WUP* should raise concern, as it is not supported by increased population demand. Even at the national level, the projected population increase between 2015 and 2050 is only +0.27%, which explains the relatively small difference between the no-deterioration and warning values. However, due to the distinct approach used for setting Germany's target value (explained in Section 4.8) the target and limit values are clearly lower than the no-deterioration thresholds (Fig. 84).

3 – In regions or states where the number of inhabitants and jobs decreases, the approach for proposing reference values was different from the one used by Schwick et al. (2018). These are the regions with minor to major waves of migration towards other places (such as parts of western Germany) or are the ones with aging population without significant birth rates. In this condition, the definition of densification changes. As the amount of built-up areas is larger than the need of the declining population, there will be vacant residential units, abandoned parcels, underused lots, and brown fields. Also, some residential units will be vacant too. Under such conditions, several planning strategies are available, one of which is infill development. This approach avoids unnecessary outward built-up area expansion by prioritizing the use of abandoned, overlooked, or underutilized land within already built-up areas, where infrastructure is typically already available (Aly & Attwa, 2013). According to a study by Schiller et al. (2021), the average overall infill development potential for East Germany is 22 m^2/inhabitant, while in West Germany it is 13 m^2/inhabitant. In shrinking regions, this indicates significant potential to repurpose underutilized areas as urban green spaces instead of undesirable built-up areas, and in

growing regions, it means that there is no actual need for urban development outside of the borders of current regions.

Another possible strategy is the conversion of brownfield sites into green spaces. Brownfields are former industrial sites that are often located in inner cities or in or near deprived neighborhoods (Gallagher & Jackson, 2008; Jacek et al., 2022). Brownfield sites offer significant potential for sustainable urban planning due to their typically central locations and the multiple benefits associated with their redevelopment. Therefore, this kind of densification is defensible, and it is vital for having a socially and environmentally sustainable city. From a social perspective, residing in areas with high vacant areas can negatively affect residents' physical and mental well-being. According to a study about Philadelphia, USA, abandoned properties often become sites for criminal activity, posing safety risks to communities (Garvin et al., 2013). From an environmental standpoint, transforming brownfields and underused properties into green areas increases green space per capita, thereby contributing to improved environmental sustainability, mental wellbeing, and climate adaptation.

In this study, reference values are proposed at the national, federal, and regional levels, while the municipal level is excluded. Land-consumption targets at higher administrative levels must ultimately be implemented locally, as the reduction in land consumption is only achievable through the self-commitment of local authorities. However, there is a problem: real estate and construction are among the economy's leading sectors in each country, and usually, there is competition among municipalities for further development. Efforts by individual municipalities to limit land consumption might be undermined if others attract inhabitants and businesses through lower land prices (Mascarenhas et al., 2019; Meyer et al., 2021). Current governance measures for managing land consumption and soil sealing primarily rely on informal tools, such as information for municipalities, practitioners, or citizens. Therefore, there is a major need for a better mix of legal planning instruments and economic taxes (Meyer et al., 2021).

In January 2024, Switzerland adopted a no-deterioration limit as part of its sustainable land-use policy, which requires the level of urban sprawl to remain below the 2022 value (Federal Office for Spatial Development, 2024).

In 2024, Esha Sharma proposed a de-sprawl approach for Switzerland in which unnecessary settlements that are not functional, based on a set of criteria will be deconstructed, equivalent to 27% of the current floor area. The scenario retains buildings within or near functional neighbourhoods (defined as areas integrated with infrastructure and basic services that meet decent living standards), while removing others, except for agricultural, industrial, protected, and historical sites. This approach could potentially halve urban sprawl.

As an example, applying such targets and limits on Sachsen (with around 18% decrease in the number of inhabitants and jobs projected), would reduce the level *WUP* from 4.044 UPU/m² in 2015 to 2.953 UPU/m² by 2050. This would reduce the level of urban sprawl from a intermediate-to-high range to a low-to-intermediate range.

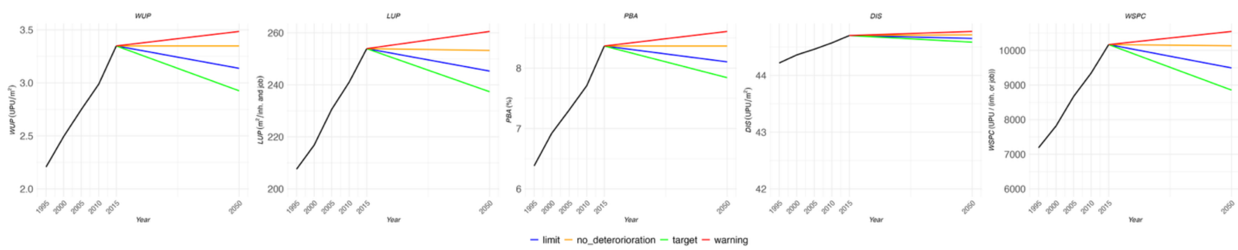

Figure 84 - Targets, limits, no-deterioration and warning values compared to WUP values of 1995-2015 in Germany

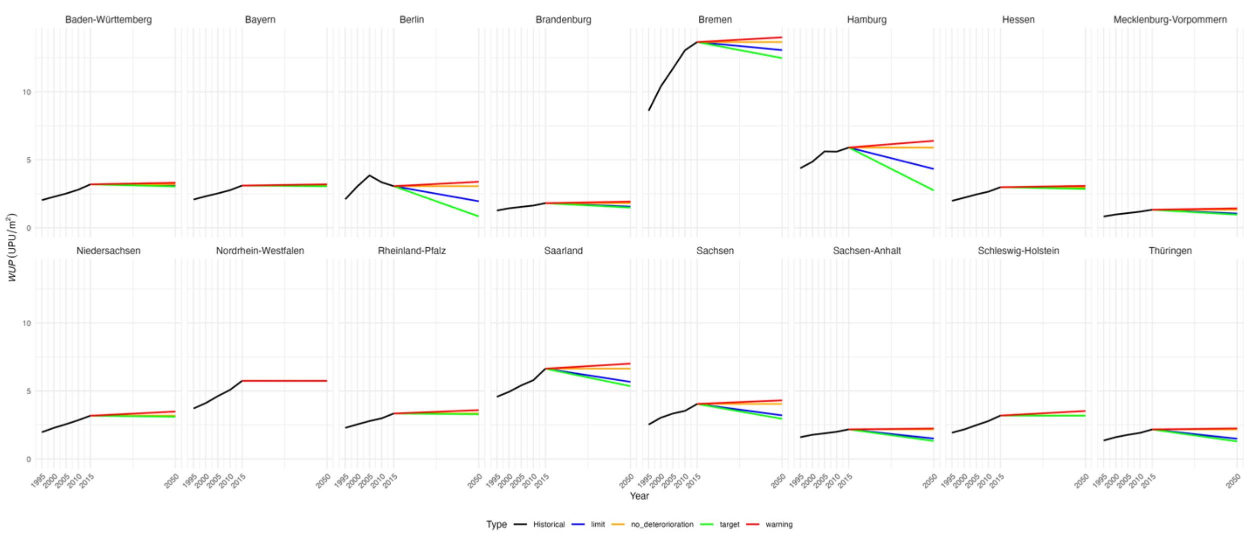

Figure 85 – Targets, limits, no-deterioration and warning values compared to WUP values of 1995-2015 across the 16 federal states of Germany

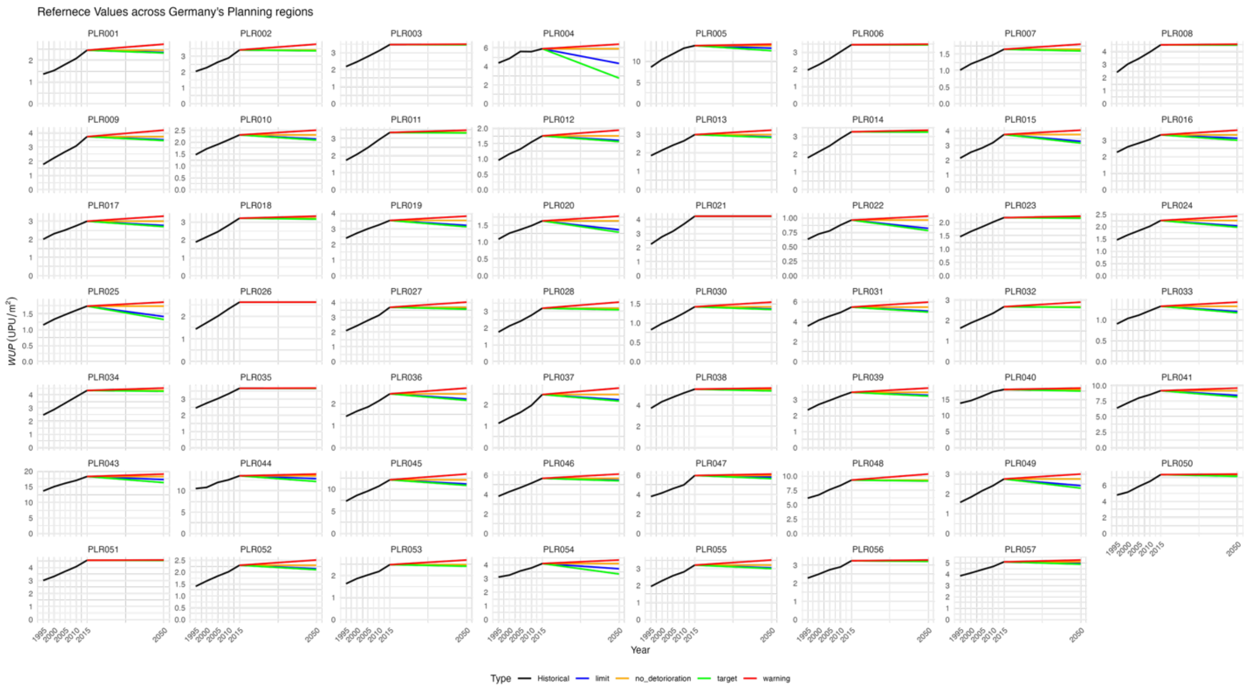

Figure 86 - Targets, limits, no-deterioration and warning values compared to WUP values of 1995-2015 across the planning regions of Germany (in PLR001-PLR057)

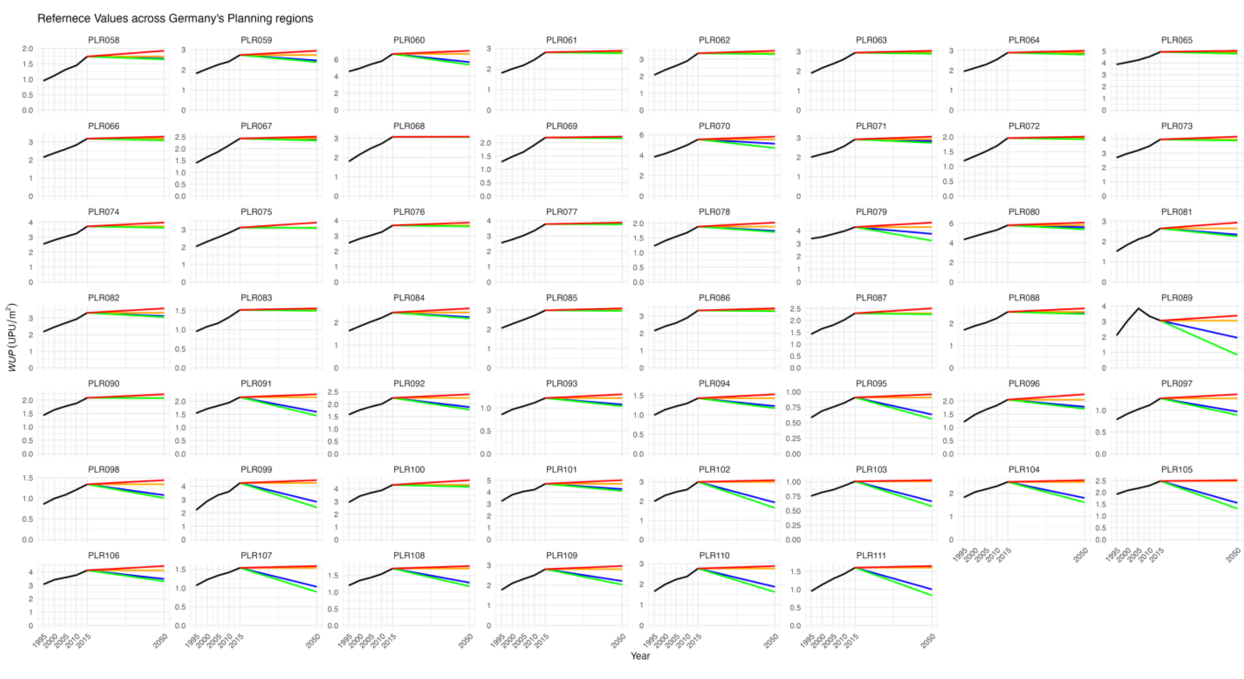

Figure 87 - Targets, limits, no-deterioration and warning values compared to WUP values of 1995-2015 across the planning regions of Germany (in PLR058-PLR111)

5-5- Strengths and Limitations of the study

This research presents a novel approach by introducing a quantitative reference framework for evaluating the effectiveness of planning policies related to urban sprawl in Germany's planning regions and federal states. It quantifies past trends of urban sprawl (1995–2015) using the Weighted Urban Proliferation (*WUP*) method and provides five alternative future scenarios. These scenarios serve as a framework to propose targets, limits, and warning thresholds as benchmarks for assessing whether future planning measures are aligned with sustainability goals. Schwick et al. (2018) applied six scenarios to urban sprawl in Switzerland, and Mosharafian (2023) extended this approach to Montreal. Both studies were done in a context marked by population growth. This study is the first to introduce such reference values in regions undergoing population decline. By incorporating both types of regions with growing and declining populations, the study broadens the discussion around sustainable land management in diverse demographic contexts.

Despite these contributions, the study faces some limitations. A primary constraint was limited data availability. The most recent reliable dataset on built-up areas goes back to 2015, which creates a gap between the base year and the start of the future scenarios in 2021. This six-year gap reduces the continuity between historical trends and future projections.

Additionally, the population and employment projections used in this study were based solely on the QuBe dataset, which offers only one future projection at the district level. As the population and jobs dynamics have a significant impact on the *WUP* value, the lack of low, medium, and high scenarios limits the analysis. Furthermore, the available projections extend only to 2040, representing a medium-term horizon. However, long-term foresight is essential for planning in contexts such as shrinking cities, where strategic decisions regarding the extent of built-up area reduction require projections that would extend far beyond 2040.

This study provides the first framework for establishing reference values for urban sprawl in Germany. While the national goal of limiting land consumption to less than 30 hectares per day was proposed by the Federal Statistical Office of Germany (2021), it does not directly address urban sprawl. In this research, urban sprawl is measured through a combination of its three core components (*PBA*, *LUP*, and *DIS*) across three spatial levels: national, federal, and regional. For each reporting unit, four kinds of reference values are proposed: targets, limits, warning values, and no-deterioration thresholds. Therefore, this positions my study among the first to comprehensively analyze these issues in the German context.

Planning processes typically operate across multiple administrative levels (municipalities, regions, federal states, etc.). While the proposed reference values provide a broad framework, their implementation also requires more localized consideration. Specific characteristics such as regional planning geography, existing bylaws, and public opinion must be taken into account. However, these kinds of evaluations fall beyond the scope of this study.

6 – Conclusion

Urban sprawl is a widely criticized form of development with numerous negative consequences. Given the global trends of rapid urban expansion, identifying and implementing sustainable strategies to better manage urban growth has become increasingly critical. Hersperger et al. (2017) emphasized the importance of evaluating the outcomes of urban planning and highlighted the lack of a structured framework and associated reference values for such evaluations. This study proposes a quantitative reference framework for evaluating planning measures, including targets, limits, and warning values for urban sprawl within Germany's planning regions and federal states.

Urban sprawl across Germany between 1995 and 2015 has been measured quantitatively by employing metrics of Weighted Urban Proliferation (*WUP*) and Weighted Sprawl per Capita (*WSPC*). The proposed reference values are based on five potential development scenarios, including "Business as Usual", "Constant *LUP*", "*WUP* mirrors population and employment trends", "Constant urban sprawl", and "Densification". Each scenario represents a potential future pathway, with scenario 1 being the least sustainable and scenario 5 the most sustainable.

According to the results of this study, Germany's planning regions and federal states have shown continuous upward trends in urban sprawl. In Germany, *WUP* increased by 51.67% from 2.207 UPU/m^2 to 3.348 UPU/m^2 between 1995 to 2015. The rate of increase in urban sprawl is 7.2 times greater than the rate of increase in the number of inhabitants and jobs. Moreover, 5 out of 16 states experienced a decline in the number of inhabitants and jobs between 1995 and 2015; however, *WUP* still increased rapidly in these regions.

If the problem of sprawl is neglected and *LUP* continues to increase in line with the current trend (scenario 1), *WUP* value will reach 4.711 UPU/m^2 by 2050 across Germany. However, if a more sustainable approach such as densification is adopted, the level of *WUP* in Germany can be significantly reduced by 2050, reaching 2.925 UPU/m^2. In general, any scenario in which the increase in urban sprawl exceeds the rate of population growth cannot be considered aligned with sustainability targets. In growing regions (regions with increasing number of inhabitants and jobs), the relative increase in urban sprawl is significantly higher than population growth in scenario 1 (by a factor of 13.86 on average), slightly higher in scenario 2 (by a factor of 1.11 on average), and similar in scenario 3 (factor of 1). However, this trend reverses in scenarios 4 and 5 (by factors of 0 and -0.66, respectively). In shrinking regions (regions with decreasing number of inhabitants and jobs), the relative increase in urban sprawl is highest under scenario 1. In fact, it is the only scenario in which urban sprawl continues to increase despite population decline. This highlights that controlling urban sprawl through appropriate planning measures is more feasible in regions experiencing population decline, as densification achieved by reducing *PBA* can be justified by the reduced demand for housing and other land uses.

In this study, reference values (targets, limits, and warning thresholds) were defined using a method similar to Schwick et al. (2018), with certain adaptations to better reflect the demographic trends and planning context of Germany. The ideal target for curbing urban sprawl and achieving environmental sustainability in this study is scenario 5, i.e., densification. In various regions, densification has demonstrated promising results in enhancing environmental sustainability. For example, in Vienna, the integration of densification strategies with green-space policies including a greenbelt has effectively curbed urban expansion (Brenner et al., 2024). Similarly, in Oslo, densification measures have led to a significant reduction in the loss of natural areas and farmland, alongside a notable increase in public transit use (Næss et al., 2020).

Our densification approach is implementable through various planning strategies, including infill development and conversion of brownfields, some outdoor parking lots, low-density suburbs, unused parcels, or vacant areas into green spaces or other land uses based on regional needs. In the densification scenario, no urban green space should be turned into built-up area as our aim is to either keep *PBA* constant or reduce it by 2050. If there is need for further housing, this can happen through vertical densification (constructing taller buildings, often replacing existing single-family homes and low-rise structures). Schwick et al. (2018) proposed two densification strategies for accommodating additional inhabitants and jobs in Swiss municipalities. The first involves an even distribution of additional inhabitants and jobs across all municipalities, with a certain proportion accommodated in newly developed areas. The second strategy focuses on more targeted densification, with no additional built-up areas permitted in the 20% of municipalities identified as the most sprawled, and higher densification required in lower-density communities.

This approach aligns with the European Union's "no net land take" objective and supports Germany's national goal of reducing land consumption to less than 30 hectares per day by 2030. Furthermore, densification supports SDG 11 by promoting sustainable urban growth, aligning with Indicator 11.3.1, which tracks the balance between land consumption and population growth. In this study, the densification approach is guided by population trends observed across Germany.

This study focuses on national, federal, and regional levels, excluding the municipal level. Land-consumption targets at higher administrative levels must ultimately be implemented locally, as the reduction in land consumption is only achievable through the self-commitment of local authorities. There are approximately between 11,000 and 12,500 municipalities in Germany (numbers vary among sources). Therefore, analyzing this large number of municipalities was outside the scope of this study. While targets and other reference values are usually set at higher administrative levels (e.g., 30 hectares per day land consumption in Germany), there is a vital need to break down these values into smaller administrative units. Ideal urban planning involves top, middle, and lower levels of planning. Future research should address the problem of urban sprawl at the municipal level, propose reference values, and explore potential solutions for implementing these reference values at the municipal level, which is the main operational level in the country.

Due to limited data availability, this study used 2015 as the base year, resulting in a six-year gap between the past-present analysis and future projections. It is recommended that future research incorporate more recent data to better assess current trends and improve the accuracy of projections of urban sprawl trends.

This study offers valuable insights into Germany's future urban landscape and provides important information regarding the effectiveness of current measures and potential need for adjustments to these measures. Moreover, the results of this study highlight the urgent need for action to slow down the loss of natural areas caused by the expansion of built-up areas. The findings can be integrated into future urban and regional planning as well as environmental assessment efforts in Germany. Additionally, the applied method of a quantitative reference framework can also be adapted and implemented in other countries and regions.

7-References

Alberti, M. (2005). The effects of urban patterns on ecosystem function. *International Regional Science Review*, *28*(2), 168-192.

Aly, S. S., & Attwa, Y. A. (2013). Infill development as an approach for promoting compactness of urban form. *Sustainable Development and Planning VI*, *173*, 455.

Ameen, R., Mourshed, M., & Li, H. (2015). A critical review of environmental assessment tools... *Environmental Impact Assessment Review. 55,* 110-125.

Angel, S., Parent, J., Civco, D. L., & Blei, A. (2010). *The persistent decline in urban densities: Global and historical evidence of sprawl.* Lincoln Institute of Land Policy.

Arora, N.K., Mishra, I. (2019). United Nations Sustainable Development Goals 2030 and environmental sustainability: race against time. *Environmental Sustainability 2*, 339–342.

Arribas-Bel, D., Nijkamp, P., & Scholten, H. (2011). Multidimensional urban sprawl in Europe: A self-organizing map approach. *Computers, Environment and Urban Systems*, 35(4), 263–275.

Bart, I. L. (2010). Urban sprawl and climate change: A statistical exploration of cause and effect, with policy options for the EU. *Land Use Policy*, *27*(2), 283-292.

Basommi, L. P., Guan, Q. F., Cheng, D. D., & Singh, S. K. (2016). Dynamics of land use change in a mining area: a case study of Nadowli District, Ghana. *Journal of Mountain Science*, 13, 633–642.

Behnisch, M., Krüger, T., Jaeger, J. A. G. (2022a). Wie hoch zersiedelt sind die deutschen Planungsregionen? *Natur und Landschaft*, 97(12), 551–560.

Behnisch, M., Krüger, T., & Jaeger, J. A. G. (2022b). Rapid rise in urban sprawl: Global hotspots and trends since 1990. *PLOS Sustainability and Transformation*, 1(11), e0000034.

Beltran-Peña, A., Rosa, L., & D'Odorico, P. (2020). Global food self-sufficiency in the 21st century under sustainable intensification of agriculture. *Environmental Research Letters*, *15*(9), 095004.

Bennett, E. M., Solan, M., Biggs, R., McPhearson, T., Norström, A. V., Olsson, P., ... & Xu, J. (2016). Bright spots: seeds of a good Anthropocene. *Frontiers in Ecology and the Environment*, *14*(8), 441-448.

Berry, H. L. (2007). 'Crowded suburbs' and 'killer cities': a brief review of the relationship between urban environments and mental health. *New South Wales public health bulletin*, *18*(12), 222-227.

Bhatta, B., Saraswati, S., & Bandyopadhyay, D. (2010). Urban sprawl measurement from remote sensing data. *Applied Geography*, *30*(4), 731-740.

BKG. (Ed.). (2019). *Verwaltungsgebiete 1:250 000 und 1:1 000 000 mit Einwohnerzahlen aktualisiert*. Federal Agency for Cartography and Geodesy. https://www.bkg.bund.de/SharedDocs/Produktinformationen/BKG/DE/P-2019/190114_VG250_1000.html

BMU/Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Hrsg.) (2007): Nationale Strategie zur biologischen Vielfalt. BMU. Berlin: 178 S.

Bontje, M. (2004). Facing the challenge of shrinking cities in East Germany: The case of Leipzig. *GeoJournal*, 61(1), 13–21.

Brenner, N., & Schmid, C. (2015). Towards a new epistemology of the urban? *City*, *19*(2-3), 151-182.

Brenner, A. K., Haas, W., Krüger, T., Matej, S., Haberl, H., Schug, F., Wiedenhofer, D., Behnisch, M., Jaeger, J. A. G., & Pichler, M. (2024). What drives densification and sprawl in cities? A spatially explicit assessment for Vienna, between 1984 and 2018. *Land Use Policy, 138*, 107037.

Bruegmann, R. (2008a). *Sprawl: A Compact History*. Chicago: The University of Chicago Press.

Bruegmann, R. (2008b). Point: Sprawl and accessibility. *Journal of Transport and Land Use, 1*(1), 5-11.

Burchell, R. W., & Shad, N. A. (1998). The evolution of the sprawl debate in the United States. *Hastings W.-Nw. J. Envtl. L. & Pol'y*, 5, 137.

Bürgi, M., Hersperger, A. M., & Schneeberger, N. (2005). Driving forces of landscape change-current and new directions. *Landscape ecology*, *19*, 857-868.

Campbell, S. (1996). Green cities, growing cities, just cities?: Urban planning and the contradictions of sustainable development. *Journal of the American Planning Association*, *62*(3), 296-312.

Clark, C. (1951). Urban population densities. *Journal of the Royal Statistical Society. Series A (General)*, *114*(4), 490-496.

Club, S. (2000). Sprawl costs us all: How your taxes fuel suburban sprawl. *Sierra Club Sprawl Report*.

Davis, G. (2002, July). Scenarios as a Tool for the 21st Century. In *Probing the future conference* (p. 10).

De Ridder, K., Lefebre, F., Adriaensen, S., Arnold, U., Beckroege, W., Bronner, C., ... & Weber, C. (2008). Simulating the impact of urban sprawl on air quality and population exposure in the German Ruhr area. Part II: Development and evaluation of an urban growth scenario. *Atmospheric environment*, *42*(30), 7070-7077.

Domhardt, H. J., Braun, S., Proske, M., Scheck, C., Schiller, H., & Theis, M. (2006). Freiraumschutz in Regionalplänen. Hinweise für eine zukunftsfähige inhaltliche und strukturelle Ausgestaltung. *Werkstatt: Praxis, H*, *40*.

Drexhage, J., Murphy, D. (2010) Sustainable development: from Brundtland to Rio 2012, Background paper for the high-level panel on global sustainability, United Nations, New York.

Evers, D. V. H. (2004). *Building for consumption: An institutional analysis of peripheral shopping center development in northwest Europe* (Doctoral dissertation, Universiteit van Amsterdam).

Ewing, R., Pendall, R., & Chen, D. (2003). Urban sprawl and transportation. *Transportation Research Record*, 1832, 175–183.

Ewing, R. H., & Hamidi, S. (2014). *Measuring sprawl 2014*. Smart Growth America.

Ewing, R., Lyons, T., Siddiq, F., Sabouri, S., Kiani, F., Hamidi, S., & Ameli, H. (2022). Growth management effectiveness: A literature review. *Journal of Planning Literature, 37*(3), 433-451.

Fatone, S., Elisa Conticelli, and Simona Tondelli. "Environmental sustainability and urban densification." *Sustainable city VII: Urban regeneration and sustainability* (2012): 217-228.

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). (2016). Climate Action Plan 2050. Edited by BMUB, Division KI I 1. Retrieved from Publikationsversand der Bundesregierung website: https://www.bmub.bund.de/english

Federal Office for Spatial Development. (2005). Spatial development report 2005, Abridged version. www.bbl.admin.ch/bundespublikationen

Fernandez, B., & Hartt, M. (2021). Growing shrinking cities. *Regional Studies, 56*(8), 1308–1319.

Fertner, C. Jørgensen, G. Sick Nielsen, T.A. Nilsson, K.S.B. (2016). Urban sprawl and growth management–drivers, impacts and responses in selected European and US cities. *Future Cities and Environment 2*, 9, 1–13.

Finke, L. (1993). *Berücksichtigung ökologischer Belange in der Regionalplanung in der Bundesrepublik Deutschland*. Akad. für Raumforschung u. Landesplanung.

Franz, G., Maier, G., & Schröck, P. (2006). Urban sprawl: how useful is this concept. In *Proceedings of ERSA conference papers from European Regional Science Association*.

Frenkel, A., & Ashkenazi, M. (2008). Measuring urban sprawl: how can we deal with it?. *Environment and Planning B: Planning and Design*, *35*(1), 56-79.

Fritsch, M. (2018). *Taking turns with the Earth: phenomenology, deconstruction, and intergenerational justice*. Stanford University Press.

Frumkin, H. (2002). Urban sprawl and public health. *Public Health Reports, 117*(3), 201–217. env

Gagné, S. A., & Fahrig, L. (2010). The trade-off between housing density and sprawl area: minimizing impacts to forest breeding birds. *Basic and Applied Ecology*, *11*(8), 723-733.

Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S., & Freihage, J. (2001). Wrestling sprawl to the ground: defining and measuring an elusive concept. *Housing Policy Debate*, *12*(4), 681-717.

Garvin, E. C., Cannuscio, C. C., & Branas, C. C. (2013). Greening vacant lots to reduce violent crime: a randomised controlled trial. *Injury prevention*, *19*(3), 198-203.

German Sustainable Development Strategy. (2021). Update. Berlin: The Press and Information Office of the Federal Government.

Germany's Integrated Environmental Programme 2030. (2016).

Ghazaryan, G., Rienow, A., Oldenburg, C., Thonfeld, F., Trampnau, B., Sticksel, S., & Jürgens, C. (2021). Monitoring of urban sprawl and densification processes in western Germany in the light of SDG indicator 11.3. 1 based on an automated retrospective classification approach. *Remote Sensing*, *13*(9), 1694.

Glaeser, E. L., & Kahn, M. E. (2004). Sprawl and urban growth. In *Handbook of regional and urban economics* (Vol. 4, pp. 2481-2527). Elsevier.

Giovannoni, E., & Fabietti, G. (2013). What is sustainability? A review of the concept and its applications. *Integrated reporting: Concepts and cases that redefine corporate accountability*, 21-40.

Goodland, R. (1995). The concept of environmental sustainability. *Annual Review of Ecology and Systematics*, *26*(1), 1-24.

Haber, W. (2007). Energy, food, and land—The ecological traps of humankind. *Environmental Science and Pollution Research*, *14*(6), 359–365.

Hamidi, S., & Ewing, R. (2014). A longitudinal study of changes in urban sprawl between 2000 and 2010 in the United States. *Landscape and Urban Planning*, *128*, 72-82.

Hartt, M. (2019). The prevalence of prosperous shrinking cities. *Annals of the American Association of Geographers, 109*(5), 1651–1670.

Hartt, M. (2021). *Quietly shrinking cities: Canadian urban population loss in an age of growth*. UBC Press.

Hassan, A. M., & Lee, H. (2015). The paradox of the sustainable city: definitions and examples. *Environment, Development and Sustainability, 17*, 1267-1285.

Haase, D., Kabisch, N., & Haase, A. (2013). Endless urban growth? On the mismatch of population, household and urban land area growth and its effects on the urban debate. *PLOS One*, *8*(6), e66531.

Hennig, E. I., Schwick, C., Soukup, T., Orlitová, E., Kienast, F., & Jaeger, J. A. G. (2015). Multi-scale analysis of urban sprawl in Europe: Towards a European de-sprawling strategy. *Land Use Policy*, *49*, 483–498.

Hersperger, A. M., Mueller, G., Knöpfel, M., Siegfried, A., & Kienast, F. (2017). Evaluating outcomes in planning: Indicators and reference values for Swiss landscapes. *Ecological Indicators*, *77*, 96–104.

Hersperger, A. M., Oliveira, E., Pagliarin, S., Palka, G., Verburg, P., Bolliger, J., & Grădinaru, S. (2018). Urban land-use change: The role of strategic spatial planning. *Global Environmental Change*, *51*, 32-42.

Hersperger, A. M., Grădinaru, S. R., & Siedentop, S. (2020). Towards a better understanding of land conversion at the urban-rural interface: Planning intentions and the effectiveness of growth management. *Journal of Land Use Science*, *15*(5), 644–651.

Hollander, J. B., Pallagst, K., Schwarz, T., & Popper, F. J. (2009). Planning shrinking cities. *Progress in Planning, 72*(4), 223–232.

Hume, I. V., Summers, D. M., & Cavagnaro, T. R. (2021). Self-sufficiency through urban agriculture: Nice idea or plausible reality? *Sustainable Cities and Society, 68*, 102770.

Jackson, K. T. (1987). *Crabgrass frontier: The suburbanization of the United States*. Oxford University Press.

Jaeger, J. A. G., & Fahrig, L. (2004). Effects of Road Fencing on Population Persistence. *Conservation Biology, 18*(6), 1651–1657.

Jaeger, J. A. G., Bertiller, R., Schwick, C., & Kienast, F. (2010a). Suitability criteria for measures of urban sprawl. *Ecological Indicators*, *10*(2), 397–406.

Jaeger, J. A. G., Bertiller, R., Schwick, C., Cavens, D., & Kienast, F. (2010b). Urban permeation of landscapes and sprawl per capita: New measures of urban sprawl. *Ecological Indicators*, *10*(2), 427–441.

Jaeger, J. A. G. & Schwick, C. (2014). Improving the measurement of urban sprawl: Weighted Urban Proliferation (*WUP*) and its application to Switzerland. *Ecological Indicators. 38.* 294–308. 10.1016/j.ecolind.2013.11.022.

Jargowsky, P. A. (1997). *Poverty and Place: Ghettos, Barrios, and the American City.* Russell Sage Foundation.

Jehling, M., Schorcht, M., & Hartmann, T. (2020). Densification in suburban Germany: approaching policy and space through concepts of justice. *Town Planning Review*, *91*(3), 217-237.

Johnson, M. P. (2001). Environmental Impacts of Urban Sprawl: A Survey of the Literature and Proposed Research Agenda. *Environment and Planning A: Economy and Space*, *33*(4), 717–735.

Jones, C., & Kammen, D. M. (2014). Spatial distribution of US household carbon footprints reveals suburbanization undermines greenhouse gas benefits of urban population density. *Environmental Science & Technology*, *48*(2), 895-902.

Klosterman, R. E. (2013). Lessons learned about planning: Forecasting, participation, and technology. *Journal of the American Planning Association*, *79*(2), 161-169.

Knoepfel, P., Larrue, C., Varone, F., & Hill, M. (2011). *Public policy analysis*. Policy Press.

Kowarik, I., Fischer, L. K., & Kendal, D. (2020). Biodiversity Conservation and Sustainable Urban Development. *Sustainability*, *12*(12), 4964.

Kutlar Joss, M., Eeftens, M., Gintowt, E., Kappeler, R., & Künzli, N. (2017). Time to harmonize national ambient air quality standards. *International Journal of Public Health, 62*(4), 453–462.

Lal, R. (2020). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. *Food Security, 12*(4), 871-876.

Leyden, K. M. (2003). Social capital and the built environment: the importance of walkable neighborhoods. *American Journal of Public Health*, *93*(9), 1546-1551.

Li, W., El-Askary, H., Lakshmi, V., Piechota, T., & Struppa, D. (2020). Earth observation and cloud computing in support of two sustainable development goals for the river nile watershed countries. *Remote Sensing*, *12*(9), 1391.

Lumeng, L. I. U., & Jianguo, W. U. (2022). Scenario analysis in urban ecosystem services research: Progress, prospects, and implications for urban planning and management. *Landscape and Urban Planning*, *224*, 104433.

Majone, G. (2002). The European Commission as regulator. In G. Majone, *Regulating Europe* (pp. 77–96). Routledge.

Marshall, A. (2001). *How cities work: Suburbs, sprawl, and the roads not taken*. University of Texas Press.

Martínez-Fernández, C., Audirac, I., Fol, S., & Cunningham-Sabot, E. (2012). Shrinking cities: Urban challenges of globalization. *International Journal of Urban and Regional Research, 36*(2), 213–225.

Mascarenhas, A., Haase, D., Ramos, T. B., & Santos, R. (2019). Pathways of demographic and urban development and their effects on land take and ecosystem services: The case of Lisbon Metropolitan Area, Portugal. *Land Use Policy, 82*, 181–194.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens III, W. W. (2013). The limits to growth. In K. Conca & G. Dabelko (Eds.), *Green planet blues: Critical perspectives on global environmental politics* (4th ed., pp. 27–31). Routledge.

Meyer, M. A., Lehmann, I., Seibert, O., & Früh-Müller, A. (2021). Spatial indicators to monitor land consumption for local governance in southern Germany. *Environmental management*, *68*(5), 755-771.

Mok, H. F., Williamson, V. G., Grove, J. R., Burry, K., Barker, S. F., & Hamilton, A. J. (2014). Strawberry fields forever? Urban agriculture in developed countries: a review. *Agronomy for Sustainable Development*, *34*, 21-43.

Mosharafian, S. (2023). *Defining targets and limits to urban sprawl: Are proposed greenbelt scenarios sufficient to achieve these benchmarks for Montreal by 2070?* [Master's thesis, Concordia University]. Department of Geography, Planning, and Environment.

Næss, P., Saglie, I. L., & Richardson, T. (2020). Urban sustainability: is densification sufficient? *European Planning Studies*, *28*(1), 146-165.

Navamuel, E. L., Rubiera Morollón, F., & Moreno Cuartas, B. (2018). Energy consumption and urban sprawl: Evidence for the Spanish case. *Journal of Cleaner Production, 172*, 3479–3486.

Nazarnia, N., Schwick, C., Kopecky, M., Soukup, T., Orlitova, E., Kienast, F., & Jaeger, J. A. G. (2016). *Urban Sprawl Metrics (USM) toolset – User manual* (1st ed., September 8, 2016). WSL. https://www.wsl.ch/de/services-und-produkte/software-websites-und-apps/urban-sprawl-metrics-tool-usm.html

Nazarnia, N., Harding, C., & Jaeger, J. A. G. (2019). How suitable is entropy as a measure of urban sprawl? *Landscape and Urban Planning*, *184*, 32-43.

Nebel, A., Kling, A., Willamowski, R., & Schell, T. (2023). Recalibration of limits to growth: An update of the World3 model. *Journal of Industrial Ecology*, *00*, 1–13.

Newman, P. W., & Kenworthy, J. R. (1988). The transport energy trade-off: Fuel-efficient traffic versus fuel-efficient cities. *Transportation Research Part A: General*, *22*(3), 163-174.

Nong, D. H., Lepczyk, C. A., Miura, T., & Fox, J. M. (2018). Quantifying urban growth patterns in Hanoi using landscape expansion modes and time series spatial metrics. *PLOS ONE*, *13*(5), e0196940.

OECD. (2018). *Rethinking urban sprawl: Moving towards sustainable cities*. OECD Publishing.

OECD. (2020). *Decarbonising urban mobility with land use and transport policies: The case of Auckland, New Zealand*. OECD Publishing.

Oswalt, P. (2006). *Shrinking cities: Volume 1. International research*. Hatje Cantz Verlag.

Pahl-Weber, E., & Henckel, D. (2008). *The planning system and planning terms in Germany: A glossary* (No. 7). Studies in Spatial Development.

Parker, D. P., & Thurman, W. N. (2013). Conservation easements: tools for conserving and enhancing ecosystem services. *Encyclopedia of Energy, Natural Resource, and Environmental Economics,* 133-143.

Pickett, S. T., Cadenasso, M. L., & Grove, J. M. (2004). Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. *Landscape and Urban Planning*, *69*(4), 369-384.

Pourali, M., Townsend, C., Kross, A., Guindon, A., & Jaeger, J. A. G. (2022). Urban sprawl in Canada: Values in all 33 Census Metropolitan Areas and corresponding 469 Census Subdivisions between 1991 and 2011. *Data in Brief*, *41*, 107941.

Pourtaherian, P., & Jaeger, J. A. G. (2022). How effective are greenbelts at mitigating urban sprawl? A comparative study of 60 European cities. *Landscape and Urban Planning*, *227*, 104532.

Prigge, W. (2006). The future of the shrinking city—Problems, options, strategies. In P. Oswalt (Ed.), *Shrinking cities: Volume 1. International research* (pp. 194–197). Hatje Cantz Verlag.

Prugh, T., & Assadourian, E. (2003). What is sustainability, anyway? *World Watch*, *16*(5), 10-10.

Pupphachai, U., & Zuidema, C. (2017). Sustainability indicators: A tool to generate learning and adaptation in sustainable urban development. *Ecological Indicators*, *72*, 784-793.

Rink, D., & Kabisch, S. (2009). Introduction: The ecology of shrinkage. *Nature and Culture*, 4(3), 223–230.

Rogan, J., & Chen, D. (2004). Remote sensing technology for mapping and monitoring land-cover and land-use change. *Progress in Planning*, *61*(4), 301-325.

Rubiera-Morollón, F., & Garrido-Yserte, R. (2020). Recent Literature about Urban Sprawl: A Renewed Relevance of the Phenomenon from the Perspective of Environmental Sustainability. *Sustainability*, *12*(16), 6551.

Scharmann, L. (2020). Introduction to the German spatial planning system. *Interreg Central Europe: Sachsen, Germany*.

Schiller, G., Blum, A., Hecht, R., Oertel, H., Ferber, U., & Meinel, G. (2021). Urban infill development potential in Germany: comparing survey and GIS data. *Buildings & Cities*, *2*(1).

Schug, F., Frantz, D., Wiedenhofer, D., Haberl, H., Virág, D., van der Linden, S., & Hostert, P. (2023). High-resolution mapping of 33 years of material stock and population growth in Germany using Earth Observation data. *Journal of Industrial Ecology*, *27*(1), 110-124.

Schwick, C., Jaeger, J. A. G., Bertiller, R., & Kienast, F. (2012). *L'étalement urbain en Suisse impossible à freiner? Analyse quantitative de 1935 à 2002 et conséquences pour l'aménagement du territoire =*

Urban sprawl in Switzerland – unstoppable? (Ruth und Herbert Uhl-Forschungsstelle für Natur- und Umweltschutz, Ed.). Haupt Verlag.

Schwick, C., Jaeger, J., Hersperger, A., Cathomas, G., & Muggli, R. (2018). *Zersiedelung messen und begrenzen: Massnahmen und Zielvorgaben für die Schweiz, ihre Kantone und Gemeinden*. Haupt Verlag.

Serageldin, I., & Streeter, A. (1993). Valuing the environment: proceedings of the first annual conference on environmentally sustainable development. In *Environmentally sustainable development proceedings series* (Vol. 2).

Skovbro, A. (2002). Urban densification–a sustainable urban policy?. *WIT Transactions on Ecology and the Environment*, *54*.

Soga, M., Yamaura, Y., Koike, S., & Gaston, K. J. (2014). Land sharing vs. land sparing: Does the compact city reconcile urban development and biodiversity conservation? *Journal of Applied Ecology, 51*(5), 998–1008.

Sousa, S. Á. D. (2010). Planning for shrinking cities in Portugal. *disP: The Planning Review, 46*(182), 29–39.

Statistisches Bundesamt Deutschland (2005) Bodenflächen nach Art der tatsächlichen Nutzung in Deutschland. *(Areas of factual use in Germany)* Available online at http://www.destatis.de/daten1/stba/html/basis/d/umw/ugrtab7.php Accessed 10 October 2006.

Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., & Ludwig, C. (2015). The trajectory of the Anthropocene: the great acceleration. *The Anthropocene Review*, *2*(1), 81-98.

Steurer, M., & Bayr, C. (2020). Measuring urban sprawl using land use data. *Land Use Policy*, *97*, 104799.

Stone, B., Hess, J. J., & Frumkin, H. (2010). Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? *Environmental health perspectives*, *118*(10), 1425-1428.

Strubelt, W. (2001). Stadt und Land. Siedlungsstruktur [City and countryside: Structure of settlement]. In B. Schäfers & W. Zapf (Eds.), *Handwörterbuch zur Gesellschaft Deutschlands* (pp. 682–695). Bundeszentrale für politische Bildung.

Torres, A., Jaeger, J. A., & Alonso, J. C. (2016). Multi-scale mismatches between urban sprawl and landscape fragmentation create windows of opportunity for conservation development. *Landscape Ecology*, *31*, 2291-2305.

Turner, B. L., Skole, D., Sanderson, S., Fischer, G., Fresco, L., & Leemans, R. (1995). Land-use and land-cover change: science/research plan. [No source information available].

Turner, G. (2008). A comparison of The Limits to Growth with 30 years of reality. *Global Environmental Change*, *18*(3), 397–411.

Turner, G. M. (2012). On the Cusp of Global Collapse? Updated Comparison of *The Limits to Growth* with Historical Data. *GAIA - Ecological Perspectives for Science and Society*, *21*(2), 116–124.

United Nations. (2015). Resolution adopted by the General Assembly on 25 September 2015. Transforming our world: the 2030 Agenda for Sustainable Development. General Assembly. Seventieth session Agenda items 15 and 116. Oct. 21st. https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E.

United Nations. (2019). Department of Economic and Social Affairs, Population Division, World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420).

United Nations Human Settlements Programme (UN-Habitat). (2020). p. 174

Wassmer, R. W. (2002). An economic perspective on urban sprawl. *California: California Senate Office of Research*, 1-21.

Wiechmann, T., & Pallagst, K. M. (2012). Urban shrinkage in Germany and the USA: A comparison of transformation patterns and local strategies. *International Journal of Urban and Regional Research*, *36*(2), 261–280.

Wilson, B., & Chakraborty, A. (2013). The environmental impacts of sprawl: Emergent themes from the past decade of planning research. *Sustainability*, *5*(8), 3302-3327.

Wissen Hayek, U., Jaeger, J. A., Schwick, C., Jarne, A., & Schuler, M. (2011). Measuring and assessing urban sprawl: What are the remaining options for future settlement development in Switzerland for 2030? *Applied Spatial Analysis and Policy*, *4*, 249-279.

Wolff, M., & Wiechmann, T. (2018). Urban growth and decline: Europe's shrinking cities in a comparative perspective 1990–2010. *European Urban and Regional Studies, 25*(2), 122–139.

World Health Organization. (2021). *WHO global air quality guidelines: Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. WHO. https://www.who.int/publications/i/item/9789240034228

Xiang, W. N., & Clarke, K. C. (2003). The use of scenarios in land-use planning. *Environment and Planning B: Planning and Design*, *30*(6), 885-909.

8 - Appendices

Appendix A: Job data of Germany

Accurate *WUP* calculation requires both population and employment data. This is because workers use built-up areas not only where they live but also where their jobs are located. Part-time workers use built-up areas for less time than full-time employees. Ideally, employment data should distinguish between full-time and part-time jobs, enabling the conversion of part-time jobs into full-time equivalents for more accurate analysis. Neither Qube nor the Federal Statistical Office provided separate data on part-time jobs; therefore, this step was not applied.

Appendix B: Relationship between *PBA* and *DIS – Federal level*

With the same approach as section 8-1-Appendix A, the relationship between *PBA* and *DIS* at federal level was estimated. Various statistical tests were conducted, including linear, quadratic, logarithmic, and log-log models. The logarithmic relationship demonstrated the highest R-squared and adjusted R-squared values, the highest F-statistic, and a very small *p*-value (table 1).

Table B-1- Statistical tests result for the relationship between PBA and DIS across Germany's federal states

Model	R-squared	Adjusted R-squared	Residual Standard Error	F-statistic	Significance (*p*-value)
Quadratic	0.8762	0.8572	0.8634	46.02	< 1.265e-06
Logarithmic	0.8996	0.8924	0.7495	125.4	< 2.263e-08
Log-Log	0.89	0.8821	0.0173	113.2	< 4.307e-08
Cubic	0.8919	0.8811	0.7879	38.04	< 2.085e-06

Based on the logarithmic relationship, the following equation describes the relationship between *PBA* and *DIS*:

$$DIS_{\text{adjusted},\,i} = 38.1078\,(\text{UPU}/\text{m}^2) + 2.8150\,(\text{UPU}/\text{m}^2)\cdot\log(PBA) + \text{Residual}_{\text{PLR}j}, \quad 0 < PBA < 100$$

Appendix C: Results of the analysis of reference scenarios

Scenario 1: Business as usual (BAU)

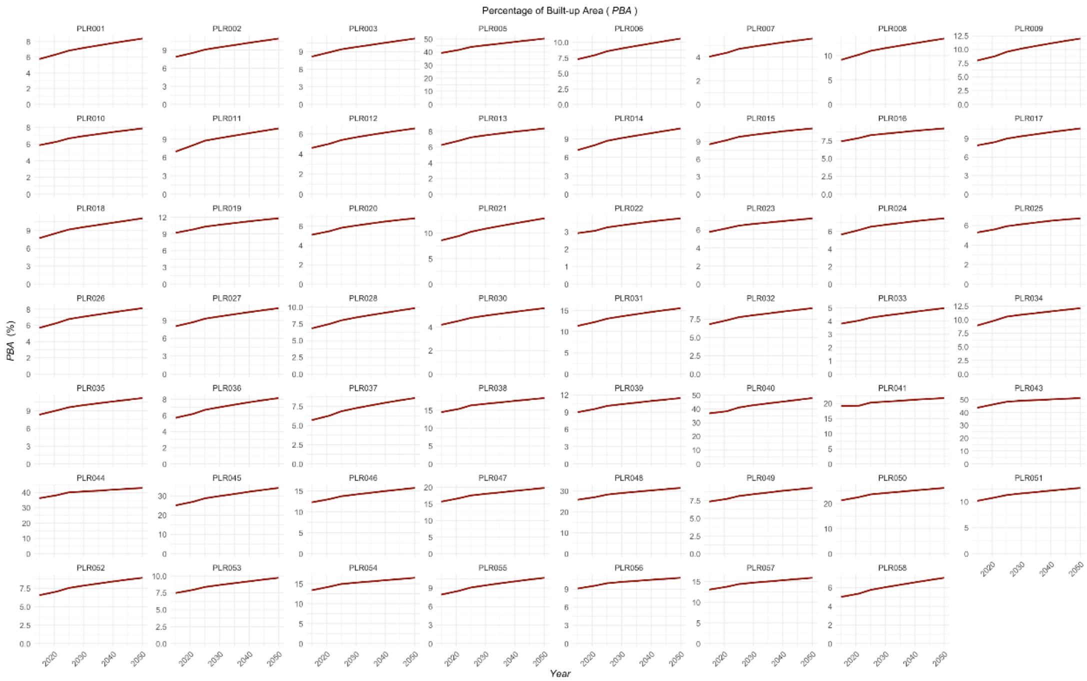

Figure C- 1- projected changes in PBA between 2015 – 2050 in scenario 1 (PLR001- PLR058)

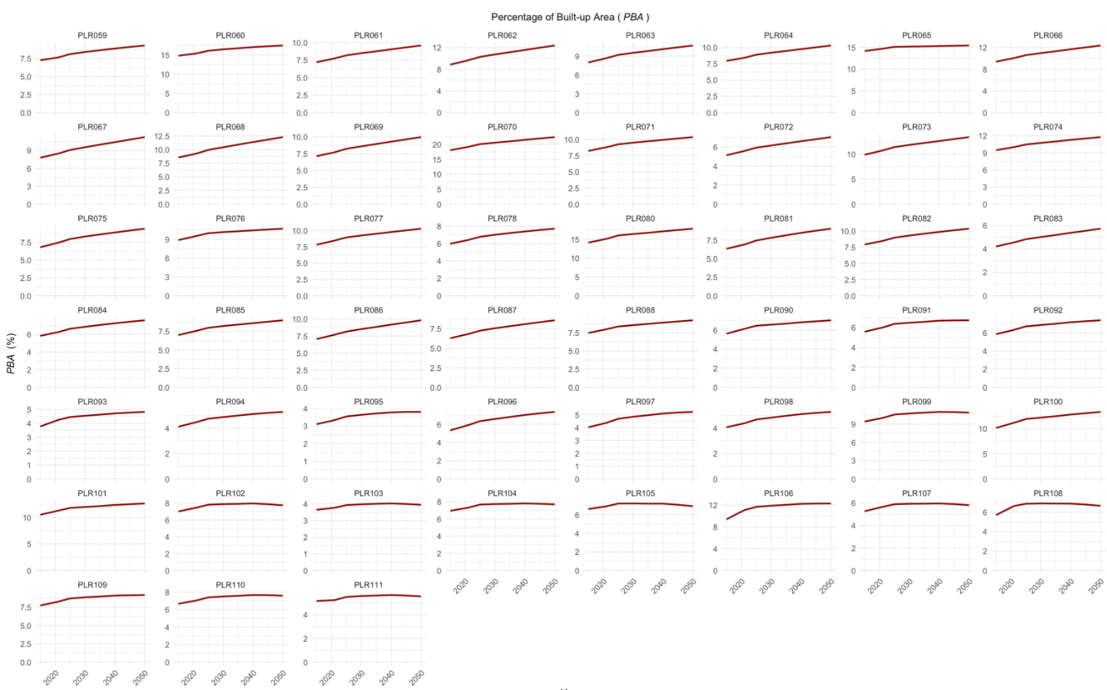

Figure C- 2 - projected changes in PBA between 2015 – 2050 in scenario 1 (PLR059- PLR111)

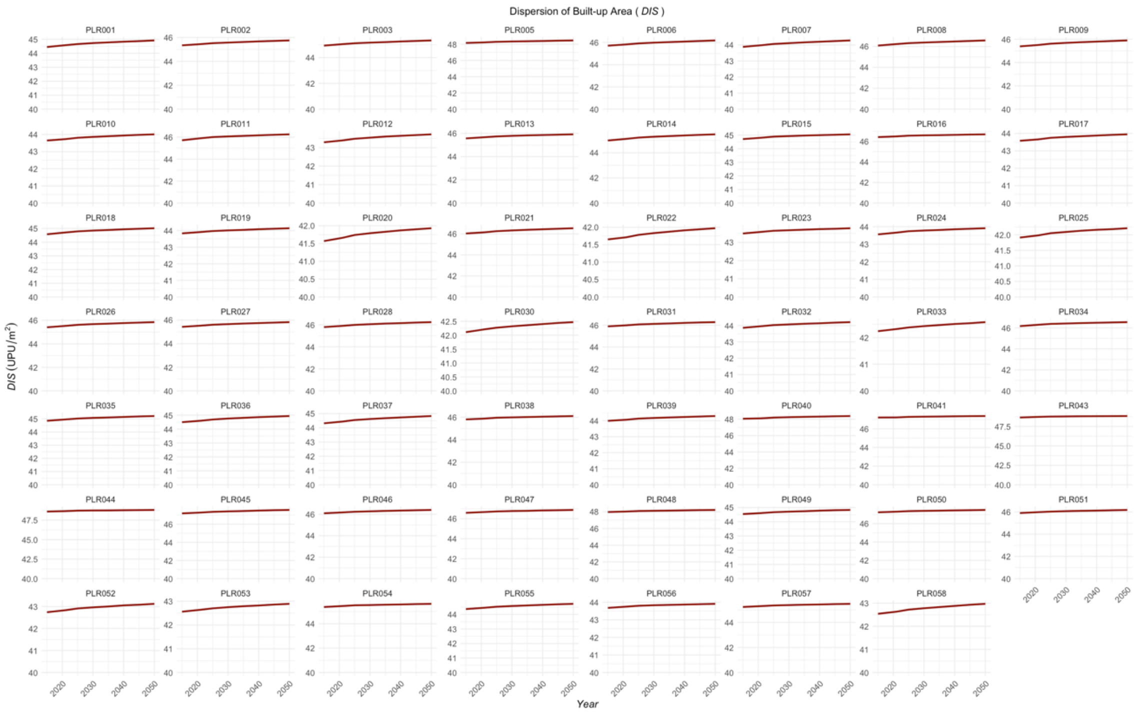

Figure C- 3 - projected changes in DIS between 2015 – 2050 in scenario 1 (PLR001- PLR058)

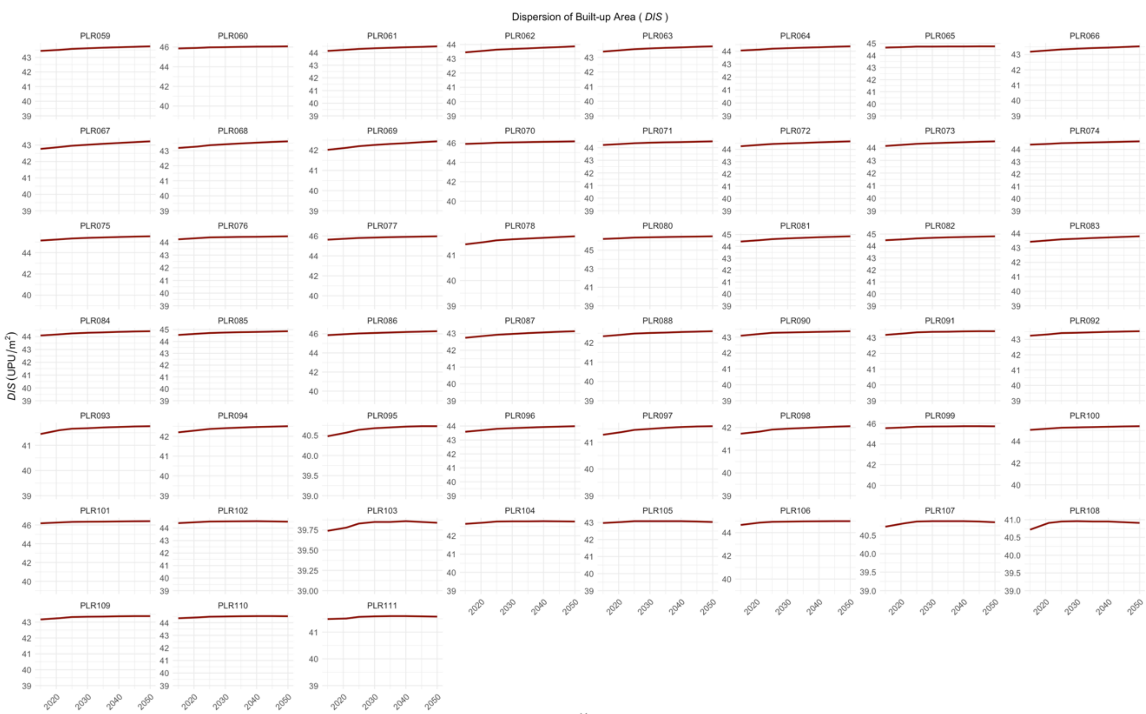

Figure C- 4- projected changes in DIS between 2015 – 2050 in scenario 1 (PLR059- PLR111)

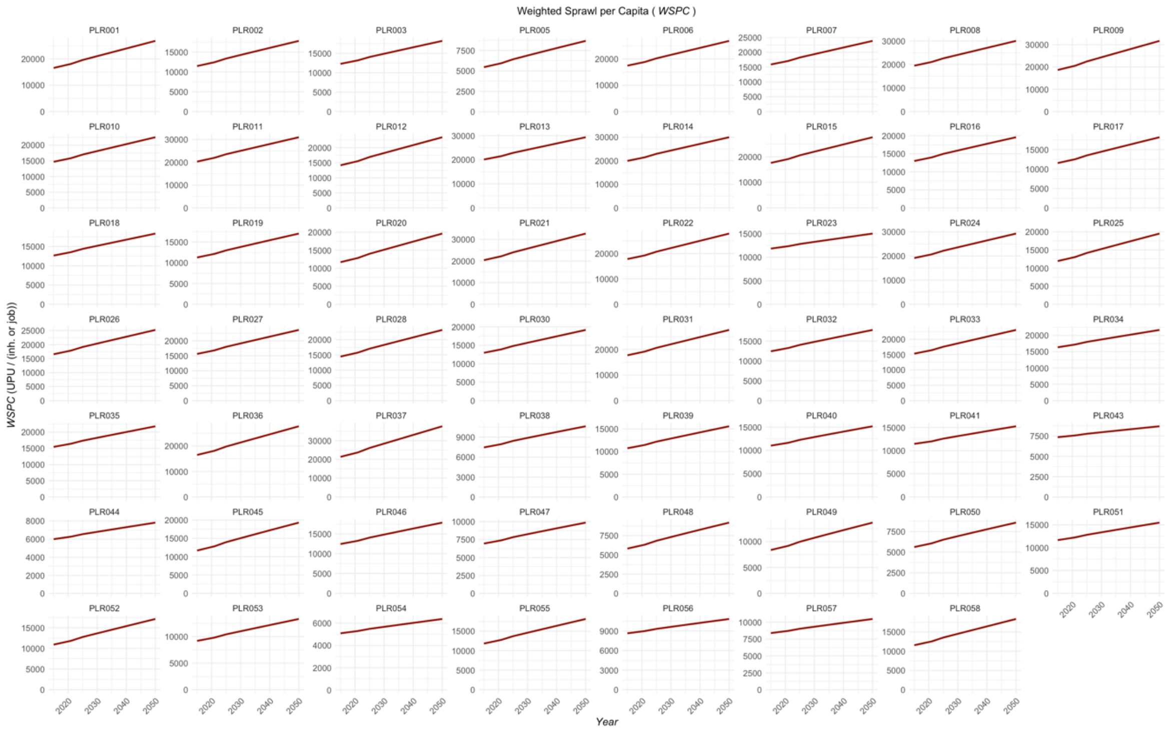

Figure C- 5 - projected changes in WSPC between 2015 – 2050 in scenario 1 (PLR001- PLR058)

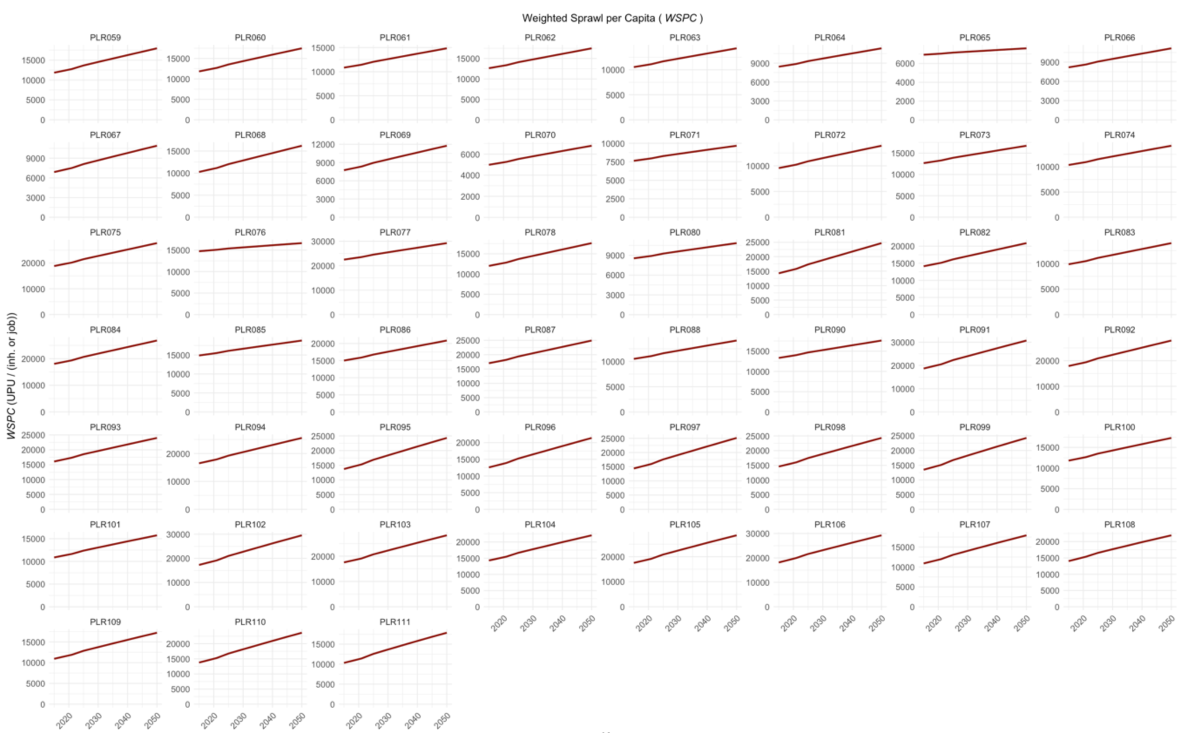

Figure C- 6 - projected changes in WSPC between 2015 – 2050 in scenario 1 (PLR059- PLR111)

Table C- 1- Urban Sprawl Metrics for Scenario 1 (BAU) in Germany's Planning Regions

	WUP (UPU/m²)			*LUP* (m²/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
PLR	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	***2015***	***2021***	***2050***
PLR001	2.47	2.79	3.85	388.1	416.3	585.3	5.78	6.40	8.39	16568	18113	26854
PLR002	3.40	3.78	5.21	266.6	281.9	373.9	7.89	8.57	10.94	11478	12444	17824
PLR003	3.47	3.86	5.21	289.3	304.2	393.2	8.17	8.90	11.25	12288	13191	18198
PLR005	13.65	15.28	22.78	157.4	162.3	191.8	39.37	41.75	50.40	5457	5940	8670
PLR006	3.44	3.83	5.39	367.9	390.8	528.4	7.26	7.94	10.60	17446	18840	26850
PLR007	1.64	1.80	2.41	392.4	415.3	552.5	4.05	4.38	5.58	15881	17062	23831
PLR008	4.50	5.11	7.09	395.0	420.1	570.9	9.13	10.18	13.49	19485	21078	30030
PLR009	3.73	4.17	6.01	400.1	433.4	633.1	8.01	8.79	12.01	18651	20557	31707
PLR010	2.31	2.51	3.30	373.2	396.4	535.9	5.86	6.28	7.86	14679	15834	22497
PLR011	3.35	3.94	5.53	421.3	447.1	601.9	6.96	8.02	10.75	20297	21967	30980
PLR012	1.75	1.94	2.68	373.2	401.7	573.0	4.61	5.02	6.55	14165	15540	23474
PLR013	2.98	3.28	4.19	422.6	446.0	586.3	6.26	6.81	8.37	20096	21494	29337
PLR014	3.26	3.69	5.17	439.3	465.1	619.8	7.18	8.01	10.71	19913	21433	29937
PLR015	3.74	4.12	5.23	400.9	428.5	594.2	8.53	9.25	11.24	17594	19099	27623
PLR016	3.52	3.81	4.75	274.1	289.3	380.4	7.42	7.88	9.23	12994	13992	19572
PLR017	2.99	3.26	4.39	305.0	324.4	441.0	7.91	8.44	10.65	11541	12522	18178
PLR018	3.22	3.66	5.00	303.9	318.5	405.8	7.74	8.61	11.07	12640	13534	18342
PLR019	3.54	3.85	4.92	293.4	309.9	408.6	9.21	9.82	11.82	11273	12140	17024
PLR020	1.63	1.78	2.34	367.2	396.7	573.6	5.12	5.49	6.83	11682	12849	19612
PLR021	4.24	4.73	6.80	413.7	443.4	621.2	8.59	9.45	12.92	20412	22217	32715
PLR022	0.96	1.02	1.30	538.3	576.1	802.7	2.91	3.05	3.76	17824	19252	27863
PLR023	2.18	2.37	2.91	313.6	322.6	376.2	5.78	6.19	7.29	11828	12333	15011
PLR024	2.25	2.49	3.15	480.1	511.1	697.0	5.64	6.15	7.49	19155	20686	29291
PLR025	1.74	1.88	2.37	362.9	390.5	555.7	5.30	5.62	6.75	11927	13042	19511
PLR026	2.63	2.96	4.01	359.0	380.7	510.9	5.70	6.30	8.13	16541	17860	25225
PLR027	3.67	4.05	5.43	340.8	360.9	481.4	8.02	8.70	11.05	15613	16814	23641
PLR028	3.18	3.56	5.00	311.1	332.2	458.7	6.84	7.50	9.87	14456	15768	23210
PLR030	1.42	1.56	2.02	383.9	405.1	532.4	4.20	4.54	5.62	12973	13906	19167
PLR031	5.46	6.00	7.96	368.4	392.9	539.6	11.34	12.27	15.52	17739	19212	27672
PLR032	2.67	2.93	3.79	316.9	332.0	422.7	6.81	7.35	9.00	12416	13238	17787
PLR033	1.32	1.42	1.83	440.4	467.2	627.6	3.81	4.04	4.98	15291	16415	23010
PLR034	4.34	4.86	6.23	336.1	348.2	420.8	8.92	9.85	12.10	16338	17185	21653
PLR035	3.65	4.03	5.19	353.1	369.6	468.8	8.35	9.08	11.17	15446	16422	21798
PLR036	2.44	2.70	3.75	385.2	416.3	603.0	5.70	6.19	8.15	16498	18146	27763
PLR037	2.46	2.75	3.95	495.3	541.2	816.9	5.71	6.29	8.59	21320	23680	37592
PLR038	5.51	6.05	8.14	195.8	202.2	240.6	14.46	15.38	18.41	7463	7954	10635
PLR039	3.46	3.75	4.79	278.6	292.0	372.2	8.99	9.56	11.45	10730	11464	15570
PLR040	18.08	19.22	26.12	224.3	232.0	278.5	36.83	38.36	47.97	11013	11625	15160
PLR041	9.18	9.35	11.29	239.2	247.1	294.5	19.17	19.25	21.81	11458	12000	15246
PLR043	18.27	19.81	23.45	176.0	178.0	190.0	43.68	46.55	51.23	7360	7575	8698

PLR044	13.47	14.62	18.65	161.5	164.2	180.3	36.30	38.28	43.01	5991	6268	7814
PLR045	12.05	13.36	18.50	242.7	258.8	355.6	25.04	26.93	34.08	11679	12839	19305
PLR046	5.67	6.14	7.87	270.4	282.8	357.3	12.31	13.08	15.76	12449	13264	17844
PLR047	5.96	6.57	8.88	182.6	187.9	219.7	15.68	16.71	19.81	6941	7392	9854
PLR048	9.30	10.26	14.52	162.0	167.4	199.6	25.89	27.15	31.56	5816	6326	9183
PLR049	2.74	2.98	3.98	224.2	237.6	317.9	7.35	7.73	9.27	8372	9178	13656
PLR050	7.34	8.16	11.41	162.9	167.8	197.1	21.28	22.55	26.23	5617	6067	8569
PLR051	4.57	4.95	6.12	259.9	268.6	320.5	10.21	10.86	12.70	11637	12227	15457
PLR052	2.29	2.51	3.39	312.5	332.2	450.5	6.56	7.06	8.92	10914	11840	17126
PLR053	2.49	2.70	3.54	275.4	288.3	365.3	7.48	7.95	9.73	9174	9793	13290
PLR054	4.10	4.48	5.78	166.1	168.4	181.9	13.36	14.25	16.48	5094	5297	6379
PLR055	3.21	3.53	4.70	292.5	309.5	411.3	7.94	8.55	10.66	11825	12775	18129
PLR056	3.24	3.46	4.16	242.1	247.8	282.3	9.09	9.56	10.86	8633	8976	10824
PLR057	5.08	5.44	6.75	215.7	220.2	246.9	13.06	13.75	15.91	8385	8709	10469
PLR058	1.74	1.89	2.66	333.6	355.7	488.1	5.01	5.36	7.06	11560	12552	18386
PLR059	2.73	2.92	3.77	315.3	333.7	444.1	7.27	7.66	9.32	11841	12740	17956
PLR060	6.64	7.03	8.50	263.9	277.5	359.0	14.80	15.38	17.46	11834	12679	17472
PLR061	2.81	3.08	4.06	277.8	288.3	351.2	7.20	7.74	9.59	10841	11457	14855
PLR062	3.35	3.73	5.05	332.6	346.3	428.7	8.84	9.65	12.38	12620	13368	17481
PLR063	2.93	3.23	4.23	287.6	298.1	360.8	8.00	8.67	10.70	10534	11120	14280
PLR064	2.89	3.13	4.14	232.5	239.7	283.0	7.96	8.44	10.33	8435	8878	11349
PLR065	4.94	5.17	5.63	198.6	200.0	208.5	14.16	14.69	15.43	6925	7042	7604
PLR066	3.18	3.48	4.63	241.4	249.5	297.8	9.39	10.05	12.37	8181	8639	11147
PLR067	2.43	2.74	4.09	221.1	232.3	299.6	7.80	8.48	11.25	6889	7503	10900
PLR068	3.07	3.40	4.88	286.6	304.1	408.7	8.56	9.27	12.30	10264	11148	16205
PLR069	2.19	2.43	3.43	252.4	265.2	341.6	7.13	7.71	9.97	7735	8346	11759
PLR070	5.56	6.11	8.30	161.8	164.9	183.6	18.03	19.16	22.44	4986	5262	6791
PLR071	2.91	3.18	4.04	215.8	220.5	248.4	8.23	8.80	10.37	7640	7966	9673
PLR072	1.96	2.19	2.99	250.3	261.3	327.4	5.14	5.59	7.05	9554	10226	13896
PLR073	3.96	4.37	5.75	314.7	325.3	389.0	9.85	10.70	13.37	12655	13291	16726
PLR074	3.73	4.01	5.01	263.8	273.8	333.4	9.48	10.01	11.77	10374	10956	14197
PLR075	3.11	3.46	4.56	411.7	434.7	572.4	6.81	7.45	9.42	18823	20167	27714
PLR076	3.68	3.99	4.58	355.8	360.5	388.5	8.89	9.54	10.71	14735	15079	16623
PLR077	3.77	4.12	5.17	466.4	482.9	582.1	7.83	8.47	10.30	22470	23513	29213
PLR078	1.88	2.05	2.58	381.1	402.0	527.6	5.98	6.41	7.71	12000	12845	17619
PLR080	5.81	6.34	8.09	207.7	212.2	238.9	14.12	15.10	17.81	8541	8905	10847
PLR081	2.64	2.94	4.11	341.1	370.0	543.2	6.33	6.89	9.03	14260	15799	24690
PLR082	3.32	3.61	4.64	336.6	355.0	465.7	7.91	8.46	10.35	14133	15144	20891
PLR083	1.52	1.68	2.27	272.2	283.7	352.9	4.20	4.55	5.72	9847	10485	13986
PLR084	2.43	2.64	3.34	433.7	459.1	611.2	5.83	6.26	7.60	18092	19399	26853
PLR085	2.99	3.27	4.02	350.0	360.1	421.0	7.02	7.59	9.01	14880	15510	18808
PLR086	3.32	3.67	4.93	319.4	333.0	414.7	7.06	7.69	9.81	15009	15899	20855
PLR087	2.30	2.53	3.32	464.1	489.6	642.5	6.28	6.81	8.57	17029	18216	24938
PLR088	2.52	2.72	3.29	312.8	324.7	396.1	7.50	8.00	9.24	10496	11061	14124

PLR090	2.09	2.31	2.75	359.8	372.9	451.8	5.63	6.14	7.04	13332	14033	17621
PLR091	2.15	2.35	2.71	486.2	526.2	766.0	5.60	6.02	6.75	18682	20500	30717
PLR092	2.25	2.47	2.98	464.4	496.4	688.3	5.84	6.32	7.37	17909	19418	27857
PLR093	1.22	1.39	1.63	497.5	527.7	708.8	3.77	4.24	4.82	16067	17358	23996
PLR094	1.43	1.58	1.93	475.4	507.6	700.8	4.11	4.47	5.28	16521	17909	25611
PLR095	0.91	0.99	1.17	470.5	516.8	794.4	3.11	3.34	3.81	13722	15297	24301
PLR096	2.05	2.32	3.08	327.7	354.1	512.3	5.34	5.91	7.37	12574	13920	21404
PLR097	1.27	1.40	1.75	455.8	498.2	752.9	4.03	4.37	5.23	14371	15968	25119
PLR098	1.34	1.46	1.84	442.2	478.6	697.0	4.07	4.38	5.28	14574	16017	24317
PLR099	4.25	4.62	5.31	298.5	327.0	497.6	9.42	10.01	10.89	13462	15108	24264
PLR100	4.31	4.85	6.17	277.8	291.5	374.0	10.15	11.17	13.34	11803	12673	17300
PLR101	4.70	5.16	6.21	243.3	254.3	320.4	10.51	11.28	12.64	10872	11639	15741
PLR102	2.99	3.23	3.44	405.5	442.5	664.3	7.02	7.47	7.75	17289	19153	29520
PLR103	1.01	1.05	1.11	636.5	688.9	1003.5	3.65	3.77	3.95	17538	19108	28245
PLR104	2.49	2.66	2.88	398.8	426.3	591.1	6.95	7.32	7.71	14304	15489	22069
PLR105	2.48	2.62	2.67	466.4	505.4	739.6	6.61	6.90	6.92	17519	19191	28543
PLR106	4.13	4.99	5.71	413.9	444.9	631.2	9.42	11.11	12.33	18130	19982	29248
PLR107	1.54	1.69	1.78	372.0	402.5	585.3	5.27	5.66	5.81	10880	11983	17939
PLR108	1.71	2.03	2.07	469.7	503.6	706.6	5.71	6.64	6.66	14029	15396	21939
PLR109	2.80	3.06	3.57	301.7	321.7	441.6	7.74	8.27	9.17	10931	11901	17208
PLR110	2.76	2.97	3.34	332.3	361.5	536.3	6.66	7.03	7.58	13766	15257	23629
PLR111	1.61	1.65	1.83	332.1	362.2	542.9	5.17	5.24	5.56	10319	11423	17851

Scenario 2: Constant *LUP*

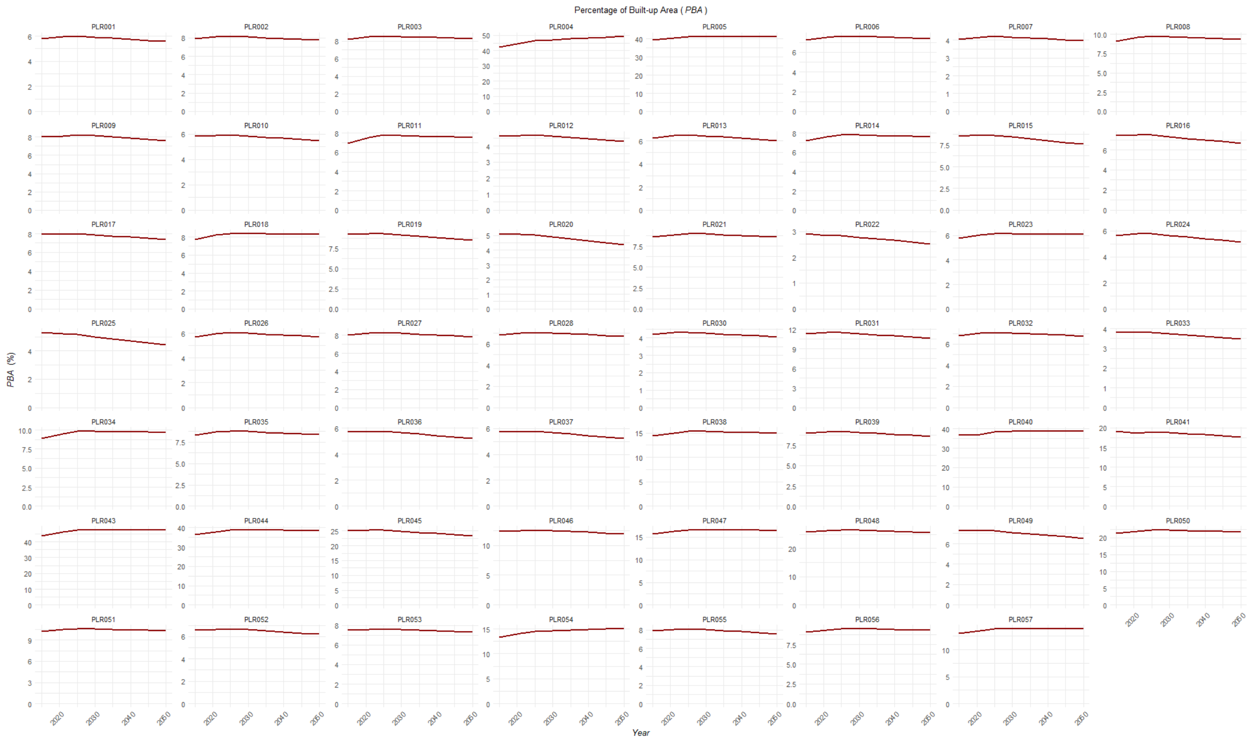

Figure C- 7- projected changes in PBA between 2015 – 2050 in scenario 2 (PLR001- PLR057)

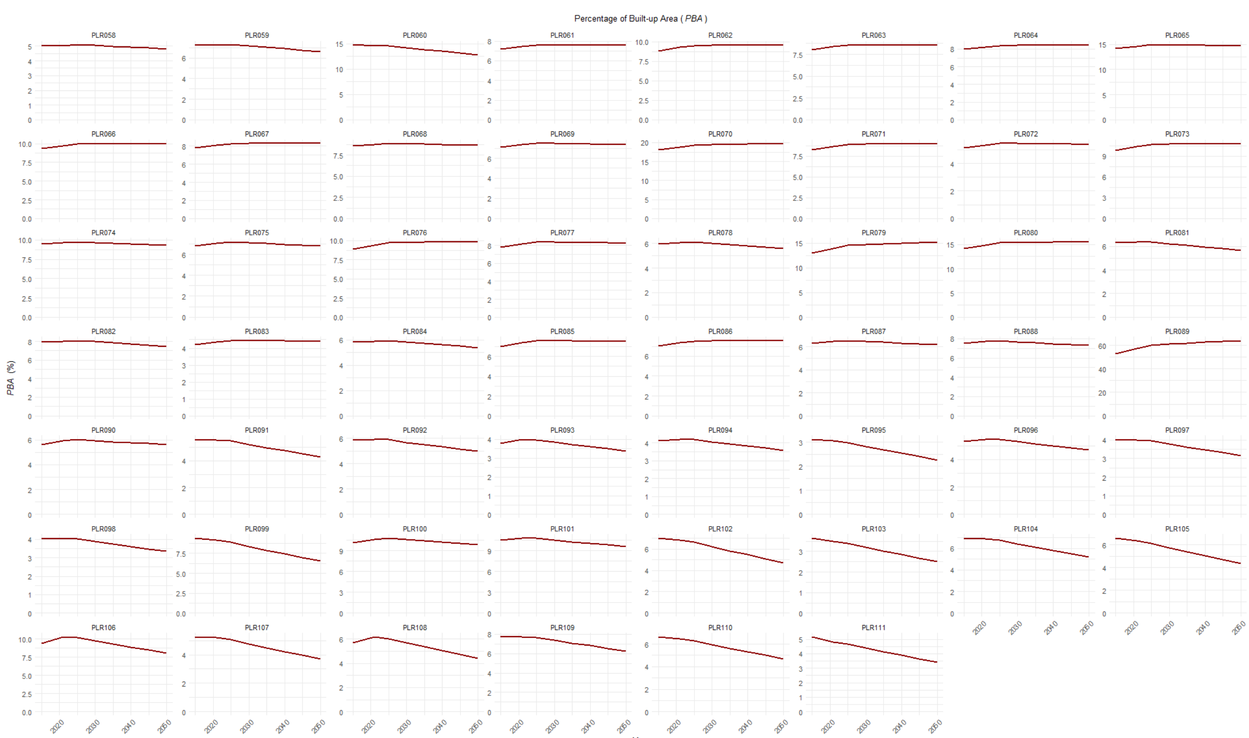

Figure C- 8- projected changes in PBA between 2015 – 2050 in scenario 2 (PLR058- PLR111)

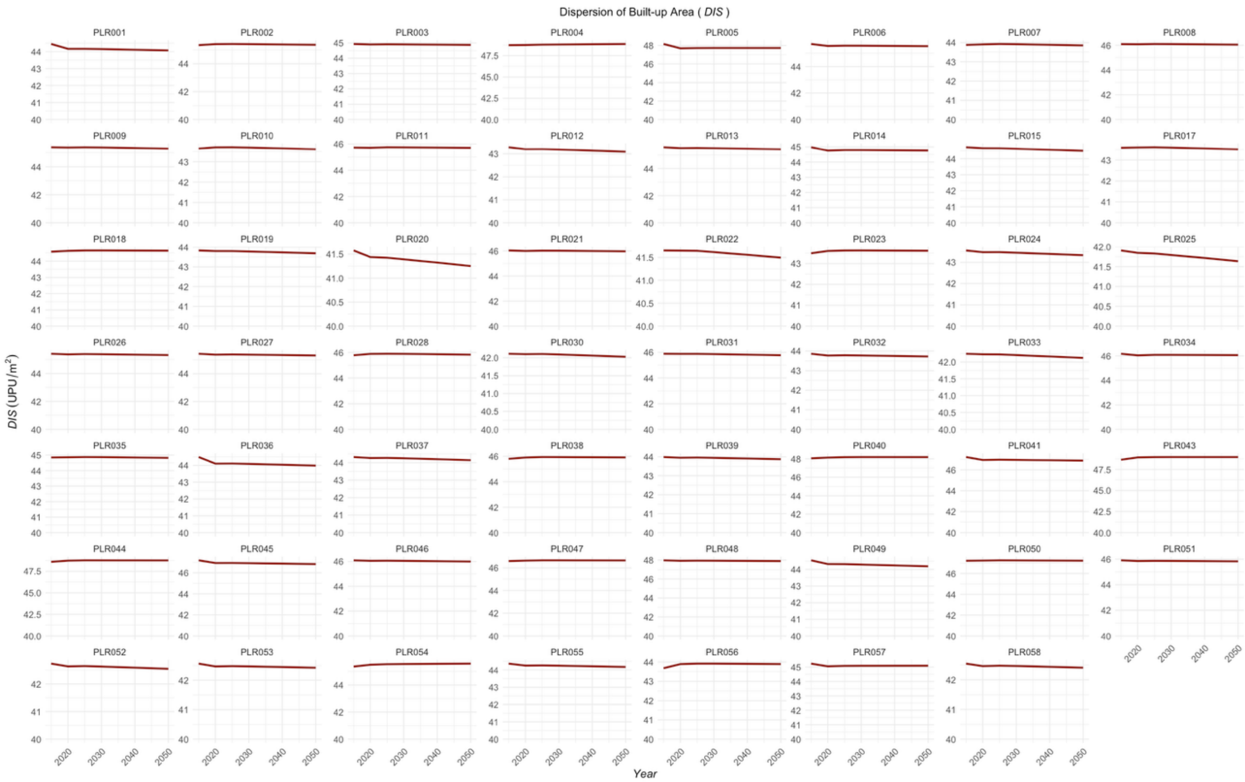

Figure C- 9- projected changes in DIS between 2015 – 2050 in scenario 2 (PLR001- PLR057)

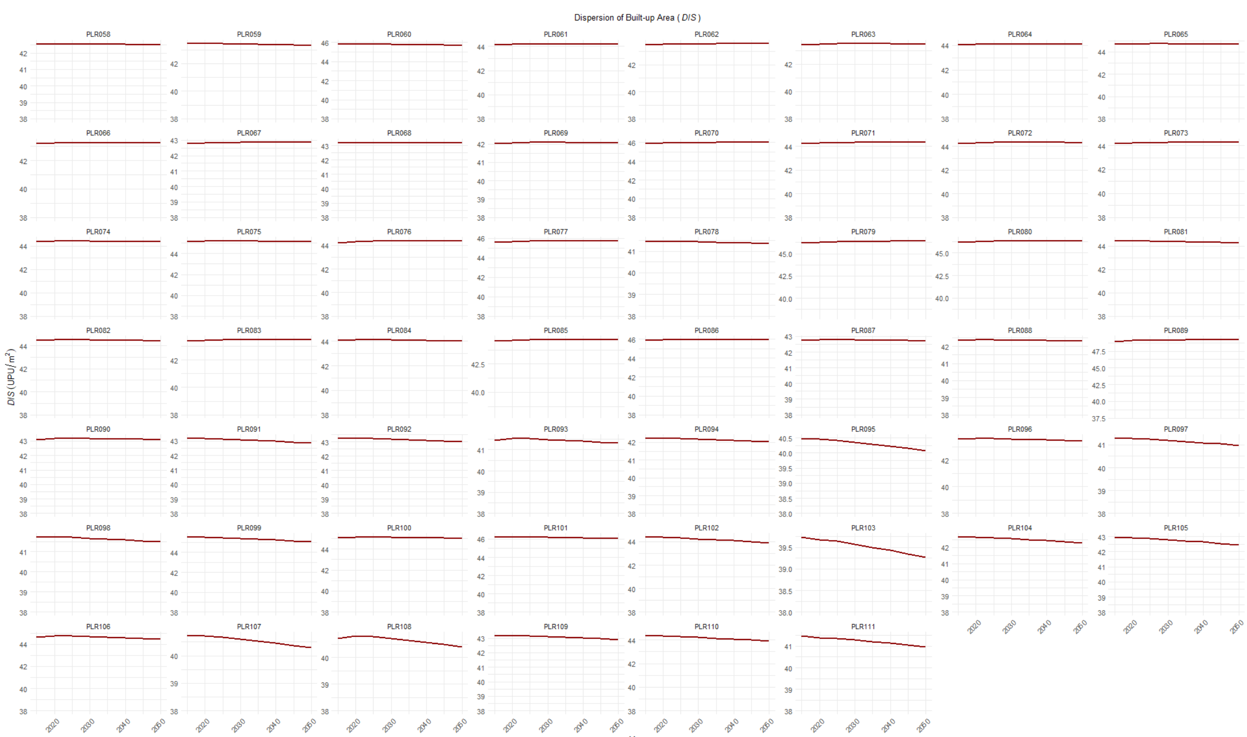

Figure C- 10- projected changes in DIS between 2015 – 2050 in scenario 2 (PLR058- PLR111)

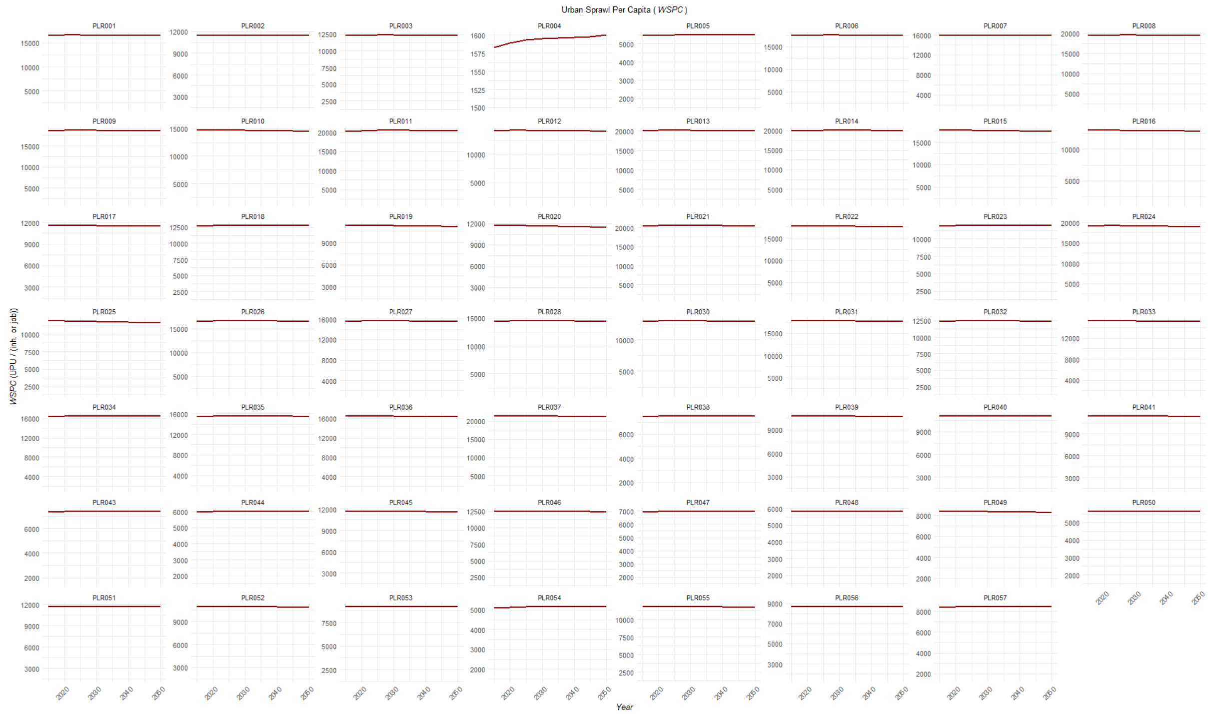

Figure C- 11- projected changes in WSPC between 2015 – 2050 in scenario 2 (PLR001- PLR057)

Figure C- 12- projected changes in WSPC between 2015 – 2050 in scenario 2 (PLR058- PLR111)

Table C- 2- Urban Sprawl Metrics for Scenario 2 in Germany's Planning Regions

	WUP (UPU/m^2)			*LUP* (m^2/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
PLR	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	***2015***	***2021***	***2050***
PLR001	2.47	2.56	2.37	388.1	388.1	388.1	5.78	5.93	5.61	16568	16631	16497
PLR002	3.40	3.50	3.35	266.6	266.6	266.6	7.89	8.07	7.82	11478	11512	11465
PLR003	3.47	3.61	3.52	289.3	289.3	289.3	8.17	8.41	8.26	12288	12336	12306
PLR004	5.91	6.29	6.98	113.1	113.1	113.1	42.26	44.70	49.09	1583	1589	1600
PLR005	13.65	14.06	14.39	157.4	157.4	157.4	39.37	40.42	41.24	5457	5469	5478
PLR006	3.44	3.56	3.51	367.9	367.9	367.9	7.26	7.44	7.36	17446	17499	17477
PLR007	1.64	1.68	1.60	392.4	392.4	392.4	4.05	4.12	3.98	15881	15921	15839
PLR008	4.50	4.75	4.61	395	395	395	9.13	9.50	9.30	19485	19577	19528
PLR009	3.73	3.79	3.52	400.1	400.1	400.1	8.01	8.10	7.66	18651	18677	18543
PLR010	2.31	2.33	2.13	373.2	373.2	373.2	5.86	5.91	5.55	14679	14695	14556
PLR011	3.35	3.67	3.65	421.3	421.3	421.3	6.96	7.45	7.42	20297	20471	20461
PLR012	1.75	1.77	1.60	373.2	373.2	373.2	4.61	4.66	4.34	14165	14187	14031
PLR013	2.98	3.08	2.86	422.6	422.6	422.6	6.26	6.42	6.07	20096	20160	20015
PLR014	3.26	3.45	3.46	439.3	439.3	439.3	7.18	7.49	7.51	19913	20029	20036
PLR015	3.74	3.80	3.29	400.9	400.9	400.9	8.53	8.63	7.76	17594	17622	17359
PLR016	3.52	3.54	3.12	274.1	274.1	274.1	7.42	7.19	6.52	12994	13003	12859
PLR017	2.99	3.00	2.76	305	305	305	7.91	7.93	7.47	11541	11545	11441
PLR018	3.22	3.44	3.48	303.9	303.9	303.9	7.74	8.13	8.19	12640	12728	12740
PLR019	3.54	3.58	3.23	293.4	293.4	293.4	9.21	9.28	8.62	11273	11285	11161
PLR020	1.63	1.62	1.36	367.2	367.2	367.2	5.12	5.09	4.52	11682	11672	11451
PLR021	4.24	4.36	4.25	413.7	413.7	413.7	8.59	8.77	8.60	20412	20465	20416
PLR022	0.96	0.94	0.82	538.3	538.3	538.3	2.91	2.86	2.60	17824	17776	17500
PLR023	2.18	2.28	2.30	313.6	313.6	313.6	5.78	5.98	6.02	11828	11887	11899
PLR024	2.25	2.31	2.04	480.1	480.1	480.1	5.64	5.75	5.26	19155	19208	18944
PLR025	1.74	1.71	1.42	362.9	362.9	362.9	5.30	5.24	4.58	11927	11904	11649
PLR026	2.63	2.75	2.63	359	359	359	5.70	5.90	5.71	16541	16614	16544
PLR027	3.67	3.77	3.58	340.8	340.8	340.8	8.02	8.18	7.86	15613	15652	15572
PLR028	3.18	3.27	3.10	311.1	311.1	311.1	6.84	6.99	6.72	14456	14495	14425
PLR030	1.42	1.46	1.36	383.9	383.9	383.9	4.20	4.28	4.08	12973	13012	12915
PLR031	5.46	5.55	5.07	368.4	368.4	368.4	11.34	11.48	10.72	17739	17765	17617
PLR032	2.67	2.76	2.64	316.9	316.9	316.9	6.81	6.98	6.76	12416	12461	12403
PLR033	1.32	1.32	1.20	440.4	440.4	440.4	3.81	3.81	3.56	15291	15290	15124
PLR034	4.34	4.65	4.74	336.1	336.1	336.1	8.92	9.41	9.54	16338	16441	16467
PLR035	3.65	3.81	3.68	353.1	353.1	353.1	8.35	8.61	8.40	15446	15513	15460
PLR036	2.44	2.45	2.21	385.2	385.2	385.2	5.70	5.72	5.30	16498	16507	16327
PLR037	2.46	2.48	2.22	495.3	495.3	495.3	5.71	5.74	5.31	21320	21337	21090
PLR038	5.51	5.70	5.73	195.8	195.8	195.8	14.46	14.84	14.92	7463	7486	7490
PLR039	3.46	3.52	3.28	278.6	278.6	278.6	8.99	9.09	8.64	10730	10749	10669
PLR040	18.08	18.21	19.04	224.3	224.3	224.3	36.83	37.05	38.45	11013	11018	11053

PLR041	9.18	8.90	8.43	239.2	239.2	239.2	19.17	18.70	17.89	11458	11430	11380
PLR043	18.27	19.32	19.96	176	176	176	43.68	45.87	47.20	7360	7387	7403
PLR044	13.47	14.01	14.36	161.5	161.5	161.5	36.30	37.58	38.40	5991	6007	6017
PLR045	12.05	12.16	11.12	242.7	242.7	242.7	25.04	25.23	23.48	11679	11687	11604
PLR046	5.67	5.77	5.47	270.4	270.4	270.4	12.31	12.48	11.98	12449	12468	12409
PLR047	5.96	6.19	6.29	182.6	182.6	182.6	15.68	16.18	16.39	6941	6964	6973
PLR048	9.30	9.45	9.19	162	162	162	25.89	26.26	25.63	5816	5823	5811
PLR049	2.74	2.72	2.41	224.2	224.2	224.2	7.35	7.30	6.65	8372	8365	8259
PLR050	7.34	7.57	7.49	162.9	162.9	162.9	21.28	21.85	21.66	5617	5631	5626
PLR051	4.57	4.72	4.62	259.9	259.9	259.9	10.21	10.47	10.29	11637	11671	11647
PLR052	2.29	2.32	2.15	312.5	312.5	312.5	6.56	6.62	6.26	10914	10930	10834
PLR053	2.49	2.54	2.44	275.4	275.4	275.4	7.48	7.58	7.36	9174	9191	9151
PLR054	4.10	4.33	4.67	166.1	166.1	166.1	13.36	13.99	14.89	5094	5121	5159
PLR055	3.21	3.27	3.05	292.5	292.5	292.5	7.94	8.05	7.65	11825	11849	11761
PLR056	3.24	3.34	3.33	242.1	242.1	242.1	9.09	9.30	9.28	8633	8662	8659
PLR057	5.08	5.25	5.44	215.7	215.7	215.7	13.06	13.42	13.79	8385	8413	8442
PLR058	1.74	1.74	1.66	333.6	333.6	333.6	5.01	5.03	4.86	11560	11566	11505
PLR059	2.73	2.72	2.46	315.3	315.3	315.3	7.27	7.24	6.74	11841	11834	11705
PLR060	6.64	6.55	5.67	263.9	263.9	263.9	14.80	14.65	13.12	11834	11820	11662
PLR061	2.81	2.92	2.98	277.8	277.8	277.8	7.20	7.41	7.52	10841	10887	10909
PLR062	3.35	3.54	3.68	332.6	332.6	332.6	8.84	9.19	9.45	12620	12694	12750
PLR063	2.93	3.08	3.15	287.6	287.6	287.6	8.00	8.30	8.43	10534	10593	10618
PLR064	2.89	2.98	3.10	232.5	232.5	232.5	7.96	8.15	8.40	8435	8463	8499
PLR065	4.94	5.10	5.15	198.6	198.6	198.6	14.16	14.53	14.63	6925	6948	6954
PLR066	3.18	3.31	3.43	241.4	241.4	241.4	9.39	9.67	9.91	8181	8218	8248
PLR067	2.43	2.53	2.61	221.1	221.1	221.1	7.80	8.03	8.22	6889	6918	6943
PLR068	3.07	3.14	3.09	286.6	286.6	286.6	8.56	8.71	8.61	10264	10290	10273
PLR069	2.19	2.26	2.27	252.4	252.4	252.4	7.13	7.30	7.33	7735	7764	7767
PLR070	5.56	5.82	6.15	161.8	161.8	161.8	18.04	18.73	19.62	4986	5007	5032
PLR071	2.91	3.07	3.23	215.8	215.8	215.8	8.23	8.56	8.90	7640	7682	7723
PLR072	1.96	2.05	2.07	250.3	250.3	250.3	5.14	5.32	5.35	9554	9600	9608
PLR073	3.96	4.19	4.40	314.7	314.7	314.7	9.86	10.26	10.63	12655	12729	12794
PLR074	3.73	3.80	3.66	263.8	263.8	263.8	9.48	9.62	9.34	10374	10396	10353
PLR075	3.11	3.24	3.10	411.7	411.7	411.7	6.81	7.01	6.78	18823	18897	18813
PLR076	3.68	3.93	4.11	355.8	355.8	355.8	8.89	9.31	9.63	14735	14834	14906
PLR077	3.77	3.96	4.00	466.4	466.4	466.4	7.83	8.12	8.17	22470	22572	22592
PLR078	1.88	1.92	1.74	381.1	381.1	381.1	5.98	6.06	5.66	12000	12023	11892
PLR079	4.29	4.60	5.07	165.7	165.7	165.7	13.07	13.87	15.05	5435	5469	5516
PLR080	5.81	6.11	6.42	207.7	207.7	207.7	14.12	14.71	15.32	8541	8580	8618
PLR081	2.64	2.66	2.34	341.1	341.1	341.1	6.33	6.35	5.79	14260	14267	14079
PLR082	3.32	3.38	3.12	336.6	336.6	336.6	7.91	8.00	7.56	14133	14156	14041
PLR083	1.52	1.59	1.61	272.2	272.2	272.2	4.20	4.34	4.37	9847	9895	9907
PLR084	2.43	2.47	2.23	433.7	433.7	433.7	5.83	5.89	5.48	18092	18122	17926
PLR085	2.99	3.15	3.21	350	350	350	7.03	7.31	7.40	14880	14964	14989

PLR086	3.32	3.48	3.58	319.4	319.4	319.4	7.07	7.32	7.48	15009	15075	15112
PLR087	2.30	2.38	2.27	464.1	464.1	464.1	6.28	6.41	6.21	17029	17088	16998
PLR088	2.52	2.59	2.44	312.8	312.8	312.8	7.50	7.66	7.33	10496	10532	10459
PLR089	3.05	3.35	3.74	94.7	94.7	94.7	52.893	57.66	64.009	546	549	553
PLR090	2.09	2.21	2.08	359.8	359.8	359.8	5.63	5.86	5.62	13332	13416	13326
PLR091	2.15	2.14	1.59	486.2	486.2	486.2	5.60	5.57	4.54	18682	18668	18066
PLR092	2.25	2.28	1.88	464.4	464.4	464.4	5.84	5.90	5.15	17909	17936	17554
PLR093	1.22	1.30	1.08	497.5	497.5	497.5	3.77	3.94	3.46	16067	16187	15849
PLR094	1.43	1.46	1.22	475.4	475.4	475.4	4.11	4.17	3.69	16521	16564	16236
PLR095	0.91	0.89	0.63	470.5	470.5	470.5	3.12	3.06	2.41	13722	13684	13193
PLR096	2.05	2.10	1.78	327.7	327.7	327.7	5.34	5.44	4.83	12574	12609	12382
PLR097	1.27	1.26	0.97	455.8	455.8	455.8	4.03	4.01	3.33	14371	14356	13939
PLR098	1.34	1.33	1.08	442.2	442.2	442.2	4.07	4.05	3.49	14574	14564	14218
PLR099	4.25	4.11	2.83	298.5	298.5	298.5	9.42	9.18	6.96	13462	13419	12942
PLR100	4.31	4.54	4.20	277.8	277.8	277.8	10.15	10.56	9.95	11803	11864	11771
PLR101	4.70	4.84	4.25	243.3	243.3	243.3	10.52	10.76	9.72	10872	10900	10774
PLR102	2.99	2.91	1.92	405.5	405.5	405.5	7.02	6.88	5.12	17289	17239	16500
PLR103	1.01	0.95	0.66	636.5	636.5	636.5	3.65	3.52	2.71	17538	17440	16786
PLR104	2.49	2.45	1.80	398.8	398.8	398.8	6.95	6.87	5.53	14304	14278	13788
PLR105	2.48	2.38	1.55	466.4	466.4	466.4	6.61	6.42	4.77	17519	17438	16623
PLR106	4.13	4.57	3.48	413.9	413.9	413.9	9.42	10.15	8.33	18130	18321	17813
PLR107	1.54	1.53	1.03	372	372	372	5.27	5.24	3.97	10880	10871	10414
PLR108	1.71	1.87	1.28	469.7	469.7	469.7	5.71	6.09	4.67	14029	14171	13593
PLR109	2.80	2.81	2.21	301.7	301.7	301.7	7.74	7.75	6.53	10931	10934	10646
PLR110	2.76	2.67	1.87	332.3	332.3	332.3	6.66	6.50	5.03	13766	13717	13208
PLR111	1.61	1.48	1.00	332.1	332.1	332.1	5.17	4.88	3.70	10319	10226	9787

Scenario 3 - *WUP* mirrors population and employment trends

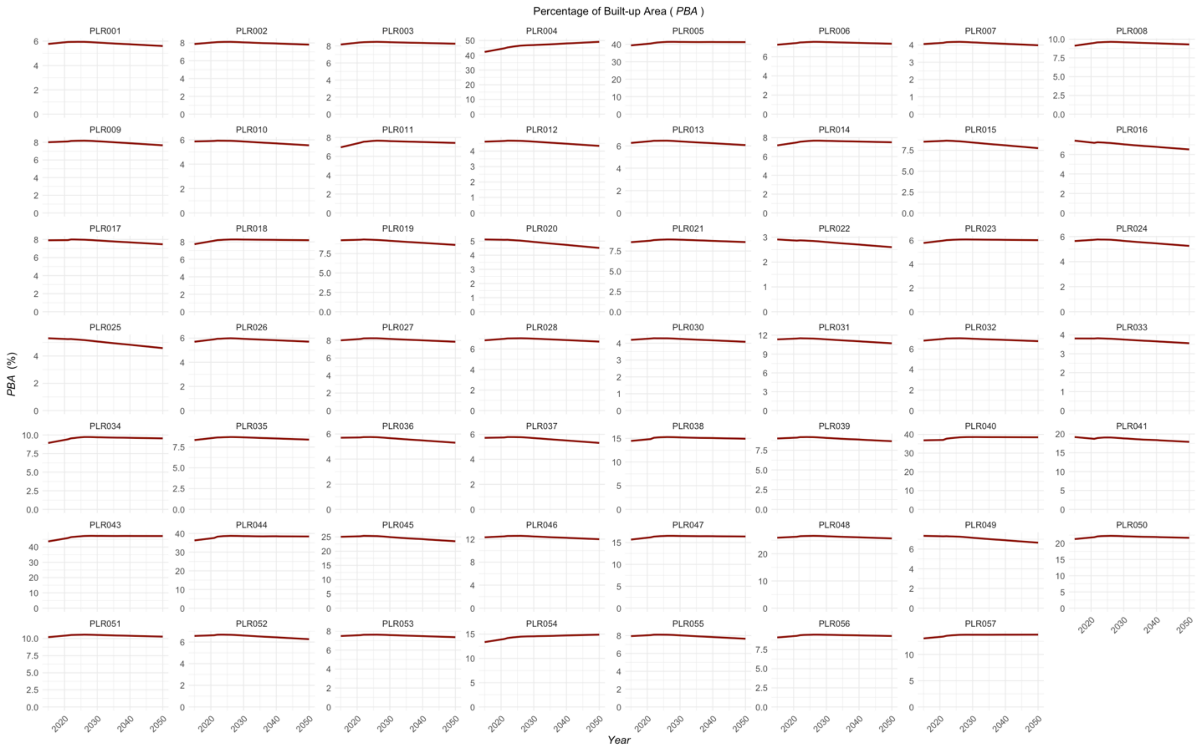

Figure C- 13- projected changes in PBA between 2015 – 2050 in scenario 3 (PLR001- PLR057)

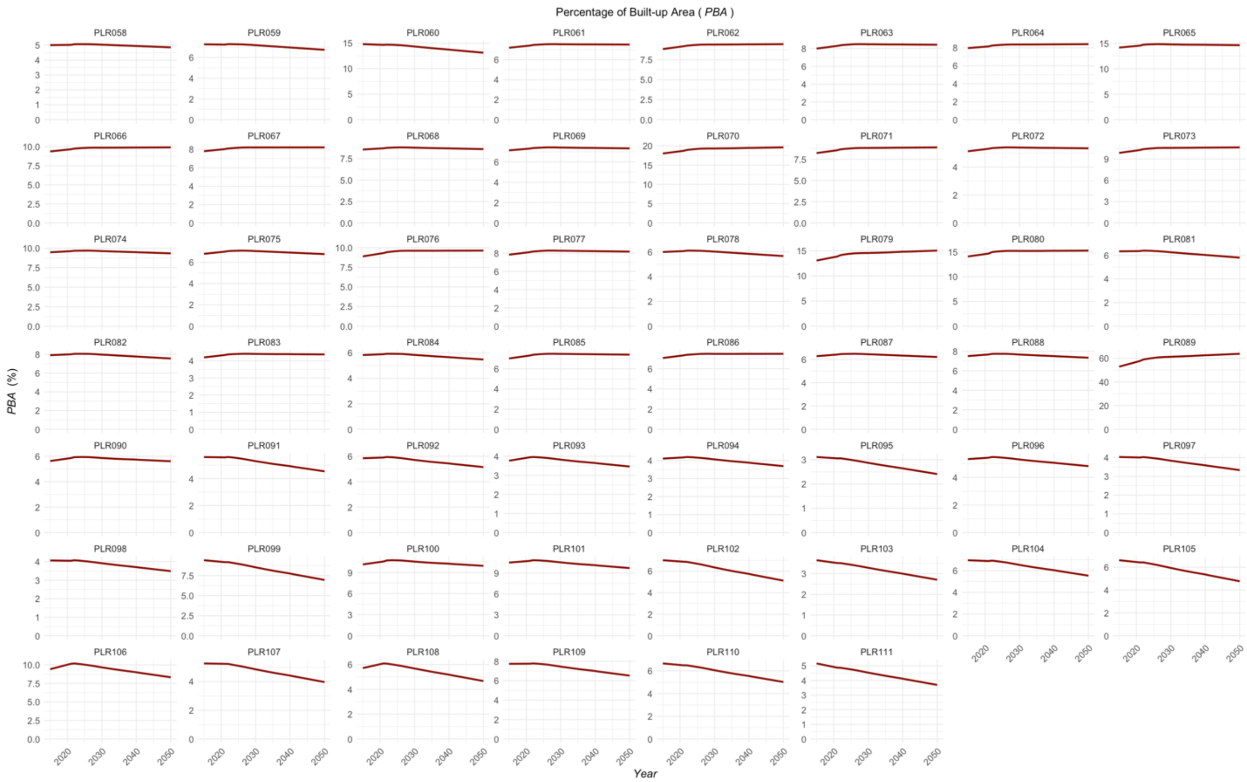

Figure C- 14- projected changes in PBA between 2015 – 2050 in scenario 3 (PLR058- PLR111)

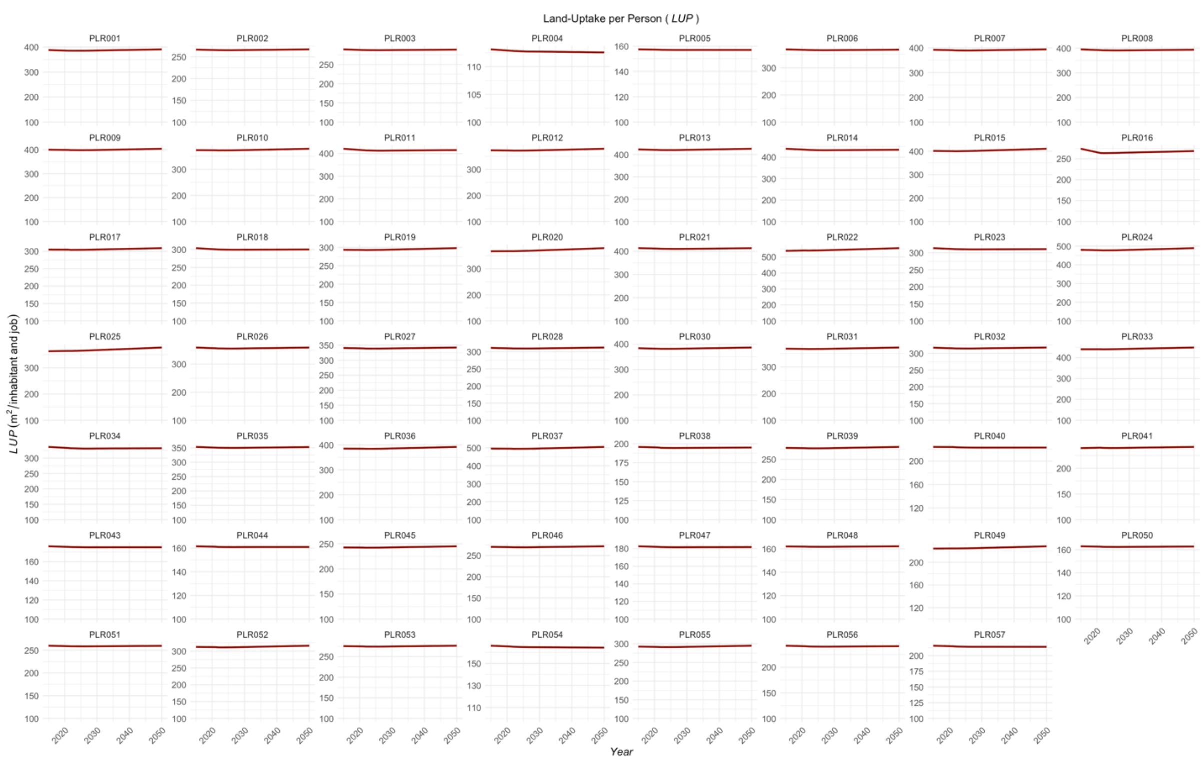

Figure C- 15- projected changes in LUP between 2015 – 2050 in scenario 3 (PLR001- PLR057)

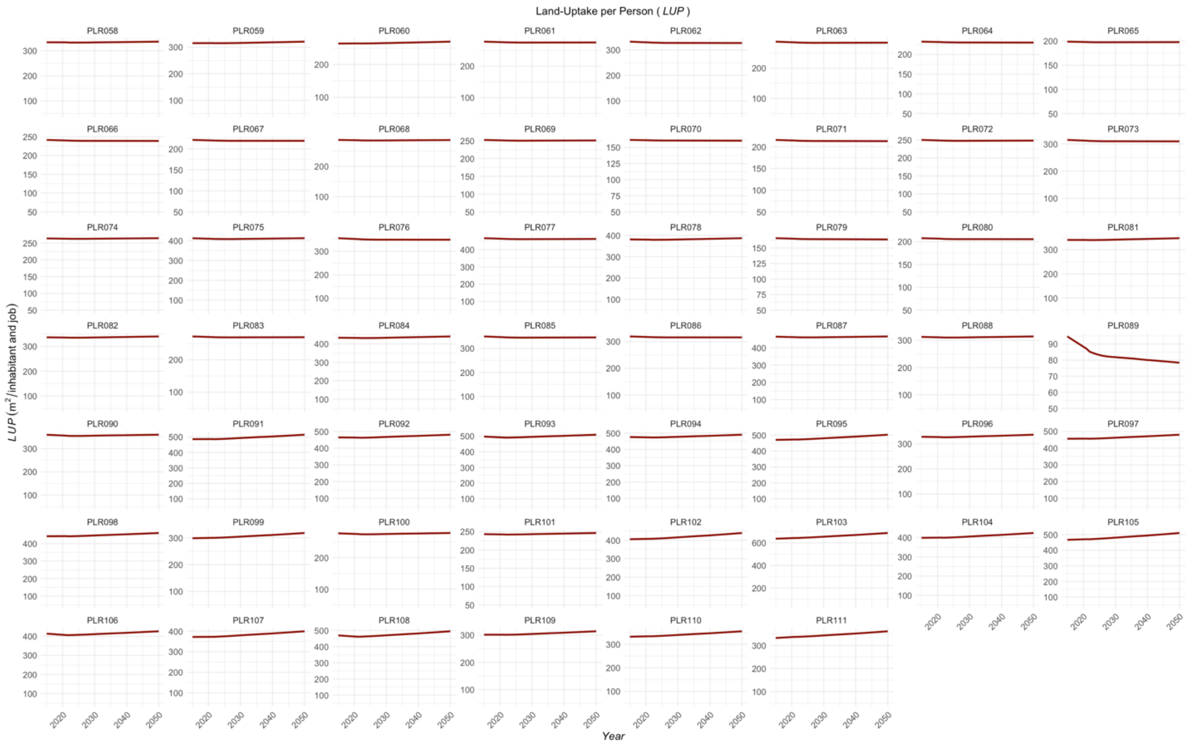

Figure C- 16- projected changes in LUP between 2015 – 2050 in scenario 3 (PLR058- PLR111)

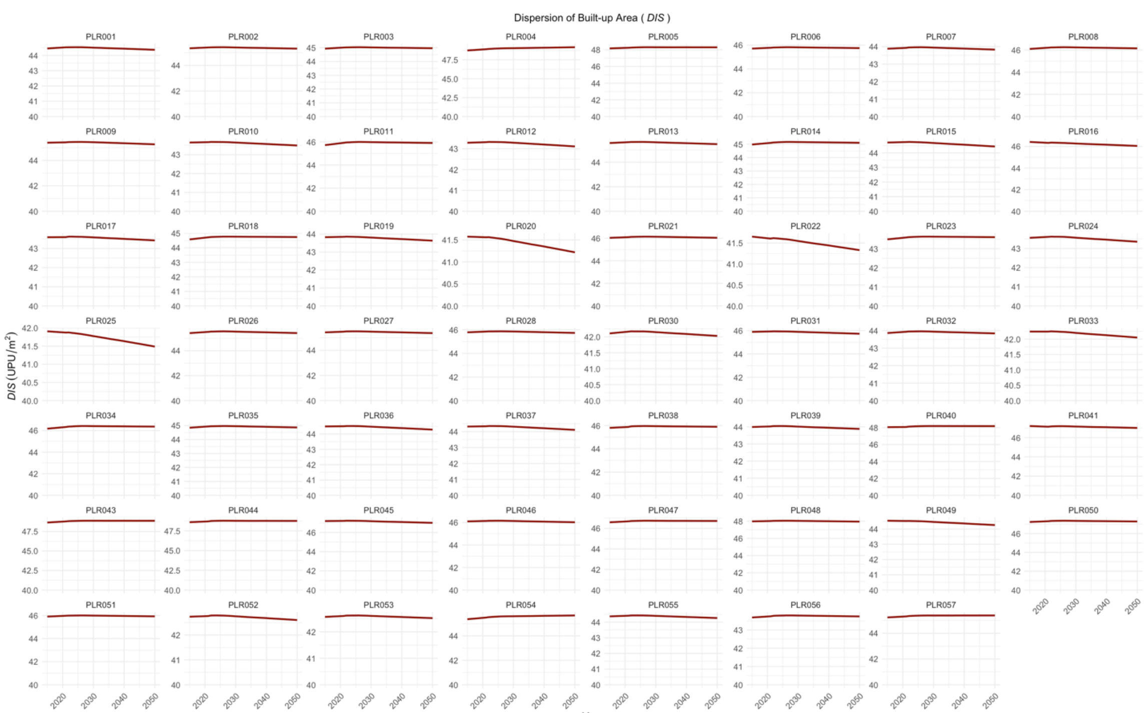

Figure C- 17- projected changes in DIS between 2015 – 2050 in scenario 3 (PLR001- PLR057)

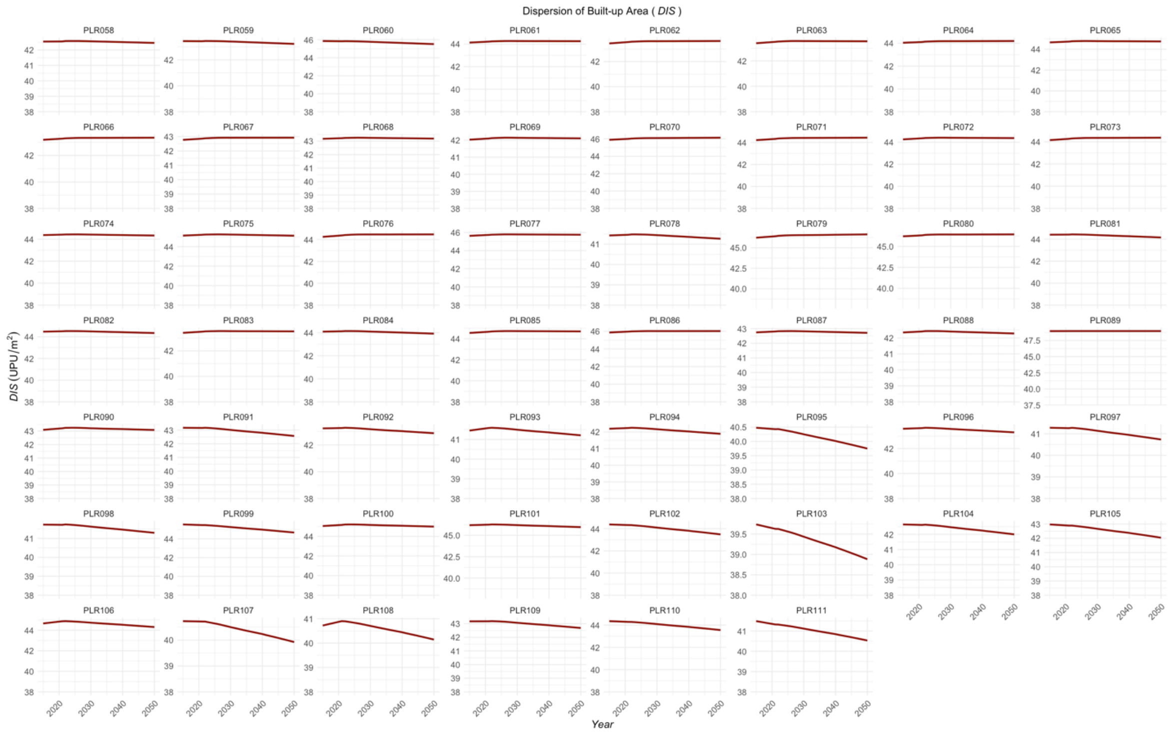

Figure C- 18- projected changes in DIS between 2015 – 2050 in scenario 3 (PLR058- PLR111)

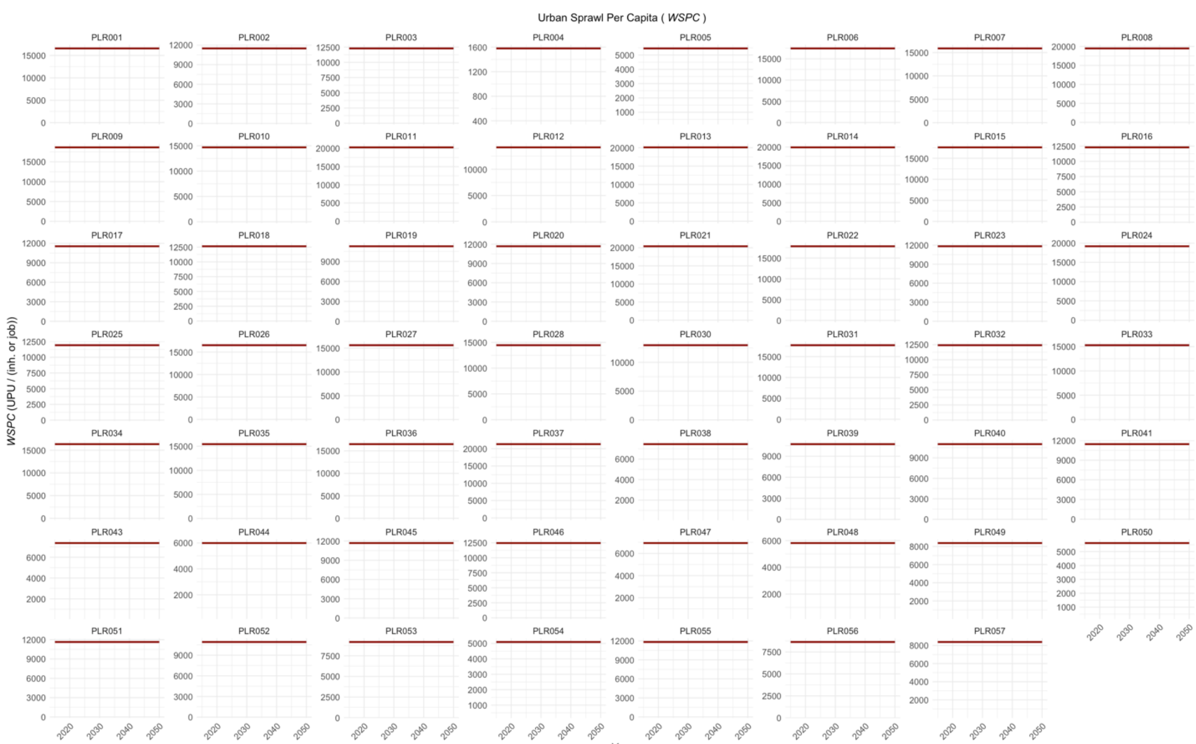

Figure C- 19- projected changes in WSPC between 2015 – 2050 in scenario 3 (PLR001- PLR057)

Figure C- 20- projected changes in WSPC between 2015 – 2050 in scenario 3 (PLR058- PLR111)

Table C- 3- Urban Sprawl Metrics for Scenario 3 in Germany's Planning Regions

	WUP (UPU/m^2)			*LUP* (m^2/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh or job))		
PLR	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**
PLR001	2.47	2.55	2.38	388.1	385.61	390.88	5.775	5.931	5.605	16567	16567	16567
PLR002	3.40	3.49	3.36	266.6	265.49	267.11	7.886	8.07	7.815	11481	11481	11481
PLR003	3.47	3.60	3.52	289.3	287.58	288.66	8.171	8.413	8.261	12288	12288	12288
PLR004	5.91	6.25	6.89	113.1	112.86	112.55	42.257	44.696	49.085	1579	1579	1579
PLR005	13.65	14.04	14.34	157.4	157.16	156.96	39.368	40.418	41.235	5460	5460	5460
PLR006	3.44	3.55	3.50	367.9	366.03	366.82	7.257	7.437	7.361	17447	17447	17447
PLR007	1.64	1.68	1.61	392.4	390.74	394.1	4.054	4.123	3.984	15880	15880	15880
PLR008	4.50	4.72	4.60	395	391.81	393.52	9.13	9.497	9.297	19485	19485	19485
PLR009	3.73	3.78	3.54	400.1	399.1	404.05	8.009	8.095	7.662	18648	18648	18648
PLR010	2.31	2.33	2.15	373.2	372.59	378.45	5.863	5.905	5.549	14681	14681	14681
PLR011	3.35	3.64	3.63	421.3	415.17	415.51	6.957	7.448	7.42	20298	20298	20298
PLR012	1.75	1.77	1.62	373.2	372.29	379.11	4.609	4.655	4.336	14167	14167	14167
PLR013	2.98	3.07	2.87	422.6	420.3	425.55	6.264	6.42	6.072	20096	20096	20096
PLR014	3.26	3.43	3.44	439.3	434.96	434.69	7.182	7.493	7.513	19914	19914	19914
PLR015	3.74	3.80	3.33	400.9	399.84	410.16	8.531	8.631	7.762	17596	17596	17596
PLR016	3.52	3.35	2.98	274.1	264.02	268.54	7.416	7.19	6.517	12291	12291	12291

PLR017	2.99	3.00	2.79	305	304.88	309.18	7.91	7.928	7.469	11543	11543	11543
PLR018	3.22	3.42	3.45	303.9	300.61	300.15	7.737	8.13	8.189	12638	12638	12638
PLR019	3.54	3.57	3.26	293.4	292.91	297.9	9.214	9.282	8.616	11272	11272	11272
PLR020	1.63	1.62	1.39	367.2	367.66	379.26	5.116	5.09	4.517	11680	11680	11680
PLR021	4.24	4.35	4.25	413.7	411.8	413.52	8.588	8.774	8.601	20409	20409	20409
PLR022	0.96	0.94	0.83	538.3	540.84	555.48	2.909	2.861	2.599	17825	17825	17825
PLR023	2.18	2.27	2.29	313.6	311.14	310.65	5.782	5.975	6.015	11826	11826	11826
PLR024	2.25	2.30	2.06	480.1	477.83	489.25	5.644	5.745	5.256	19154	19154	19154
PLR025	1.74	1.72	1.45	362.9	364.04	377.04	5.304	5.241	4.58	11927	11927	11927
PLR026	2.63	2.74	2.63	359	356.37	358.89	5.702	5.899	5.71	16541	16541	16541
PLR027	3.67	3.76	3.59	340.8	339.4	342.27	8.021	8.177	7.859	15613	15613	15613
PLR028	3.18	3.26	3.11	311.1	309.74	312.17	6.84	6.99	6.719	14454	14454	14454
PLR030	1.42	1.45	1.37	383.9	382.01	386.71	4.198	4.277	4.083	12973	12973	12973
PLR031	5.46	5.54	5.10	368.4	367.42	372.71	11.338	11.477	10.719	17736	17736	17736
PLR032	2.67	2.75	2.64	316.9	315.08	317.41	6.806	6.975	6.757	12415	12415	12415
PLR033	1.32	1.32	1.21	440.4	440.47	448.6	3.81	3.808	3.559	15291	15291	15291
PLR034	4.34	4.62	4.70	336.1	332.63	331.77	8.922	9.414	9.543	16338	16338	16338
PLR035	3.65	3.79	3.68	353.1	350.59	352.57	8.347	8.613	8.4	15445	15445	15445
PLR036	2.44	2.45	2.23	385.2	384.8	391.94	5.696	5.719	5.299	16496	16496	16496
PLR037	2.46	2.48	2.24	495.3	494.59	504.66	5.713	5.744	5.308	21319	21319	21319
PLR038	5.51	5.68	5.71	195.8	195.09	194.97	14.458	14.844	14.921	7460	7460	7460
PLR039	3.46	3.51	3.30	278.6	277.86	280.98	8.986	9.094	8.64	10730	10730	10730
PLR040	18.08	18.20	18.97	224.3	224.13	223.18	36.831	37.05	38.447	11012	11012	11012
PLR041	9.18	8.92	8.49	239.2	240.03	241.54	19.171	18.695	17.889	11457	11457	11457
PLR043	18.27	19.26	19.85	176	175.41	175.04	43.683	45.87	47.196	7364	7364	7364
PLR044	13.47	13.97	14.30	161.5	161.16	160.93	36.302	37.575	38.403	5992	5992	5992
PLR045	12.05	12.15	11.20	242.7	242.47	244.98	25.041	25.225	23.48	11680	11680	11680
PLR046	5.67	5.76	5.49	270.4	269.75	271.69	12.313	12.479	11.984	12448	12448	12448
PLR047	5.96	6.17	6.26	182.6	181.98	181.74	15.677	16.181	16.385	6940	6940	6940
PLR048	9.30	9.44	9.20	162	161.83	162.11	25.894	26.257	25.634	5816	5816	5816
PLR049	2.74	2.72	2.44	224.2	224.45	228.17	7.346	7.299	6.652	8372	8372	8372
PLR050	7.34	7.55	7.48	162.9	162.58	162.7	21.278	21.854	21.658	5619	5619	5619
PLR051	4.57	4.71	4.61	259.9	258.83	259.61	10.211	10.469	10.287	11640	11640	11640
PLR052	2.29	2.32	2.16	312.5	311.81	316.1	6.561	6.623	6.261	10915	10915	10915
PLR053	2.49	2.53	2.44	275.4	274.62	276.41	7.484	7.575	7.363	9173	9173	9173
PLR054	4.10	4.31	4.62	166.1	165.36	164.35	13.36	13.991	14.89	5096	5096	5096
PLR055	3.21	3.27	3.07	292.5	291.59	294.91	7.941	8.053	7.645	11824	11824	11824
PLR056	3.24	3.33	3.32	242.1	241.04	241.13	9.088	9.296	9.278	8634	8634	8634
PLR057	5.08	5.24	5.40	215.7	214.79	213.9	13.063	13.416	13.786	8384	8384	8384
PLR058	1.74	1.74	1.67	333.6	333.32	336.13	5.011	5.026	4.861	11559	11559	11559
PLR059	2.73	2.72	2.49	315.3	315.58	321.06	7.268	7.24	6.74	11841	11841	11841
PLR060	6.64	6.56	5.76	263.9	264.37	269.75	14.8	14.651	13.122	11834	11834	11834
PLR061	2.81	2.91	2.96	277.8	276.05	275.23	7.199	7.412	7.517	10840	10840	10840
PLR062	3.35	3.52	3.65	332.6	329.5	327.24	8.841	9.186	9.453	12619	12619	12619

PLR063	2.93	3.06	3.12	287.6	285.19	284.17	7.997	8.295	8.428	10533	10533	10533
PLR064	2.89	2.97	3.08	232.5	231.48	230.19	7.964	8.149	8.4	8433	8433	8433
PLR065	4.94	5.09	5.12	198.6	197.81	197.62	14.158	14.53	14.625	6922	6922	6922
PLR066	3.18	3.30	3.40	241.4	239.92	238.72	9.385	9.668	9.914	8179	8179	8179
PLR067	2.43	2.52	2.59	221.1	219.91	218.96	7.804	8.03	8.22	6888	6888	6888
PLR068	3.07	3.13	3.09	286.6	285.51	286.22	8.564	8.706	8.613	10264	10264	10264
PLR069	2.19	2.25	2.26	252.4	251.08	250.92	7.133	7.303	7.325	7733	7733	7733
PLR070	5.56	5.79	6.09	161.8	161.24	160.58	18.035	18.731	19.624	4986	4986	4986
PLR071	2.91	3.05	3.19	215.8	214.38	213.02	8.227	8.561	8.896	7641	7641	7641
PLR072	1.96	2.04	2.06	250.3	248.67	248.37	5.138	5.316	5.348	9555	9555	9555
PLR073	3.96	4.16	4.35	314.7	311.85	309.35	9.855	10.26	10.633	12655	12655	12655
PLR074	3.73	3.79	3.66	263.8	262.96	264.53	9.475	9.618	9.34	10371	10371	10371
PLR075	3.11	3.23	3.10	411.7	408.93	412.02	6.807	7.008	6.781	18821	18821	18821
PLR076	3.68	3.90	4.06	355.8	351.98	349.25	8.893	9.314	9.63	14738	14738	14738
PLR077	3.77	3.94	3.98	466.4	462.73	462	7.833	8.115	8.174	22470	22470	22470
PLR078	1.88	1.91	1.76	381.1	379.94	386.82	5.983	6.057	5.655	12002	12002	12002
PLR079	4.29	4.57	5.00	165.7	164.83	163.65	13.067	13.868	15.045	5437	5437	5437
PLR080	5.81	6.08	6.37	207.7	206.59	205.49	14.123	14.707	15.318	8542	8542	8542
PLR081	2.64	2.66	2.37	341.1	340.85	348.27	6.326	6.349	5.792	14261	14261	14261
PLR082	3.32	3.37	3.14	336.6	335.68	340.14	7.91	8.003	7.558	14132	14132	14132
PLR083	1.52	1.58	1.60	272.2	270.31	269.83	4.199	4.337	4.373	9848	9848	9848
PLR084	2.43	2.47	2.25	433.7	432.48	440.52	5.829	5.894	5.481	18091	18091	18091
PLR085	2.99	3.14	3.18	350	346.8	345.86	7.025	7.312	7.399	14881	14881	14881
PLR086	3.32	3.47	3.55	319.4	317.17	315.9	7.065	7.322	7.475	15010	15010	15010
PLR087	2.30	2.37	2.27	464.1	461.35	465.49	6.275	6.414	6.206	17028	17028	17028
PLR088	2.52	2.59	2.45	312.8	311.11	314.47	7.498	7.662	7.333	10494	10494	10494
PLR089	3.05	3.34	3.70	94.74	94.68	94.31	52.893	57.645	63.746	548	548	548
PLR090	2.09	2.19	2.08	359.8	356.14	360.05	5.633	5.863	5.615	13330	13330	13330
PLR091	2.15	2.14	1.65	486.2	486.85	514.9	5.6	5.574	4.539	18684	18684	18684
PLR092	2.25	2.28	1.92	464.4	463.27	480.53	5.84	5.895	5.145	17911	17911	17911
PLR093	1.22	1.29	1.09	497.5	491.27	509.21	3.767	3.944	3.462	16068	16068	16068
PLR094	1.43	1.46	1.24	475.4	473.37	489.67	4.107	4.172	3.688	16522	16522	16522
PLR095	0.91	0.89	0.66	470.5	472.68	502.95	3.115	3.06	2.413	13720	13720	13720
PLR096	2.05	2.10	1.81	327.7	326.25	335.84	5.341	5.443	4.83	12575	12575	12575
PLR097	1.27	1.26	1.00	455.8	456.62	479.85	4.033	4.007	3.334	14371	14371	14371
PLR098	1.34	1.33	1.10	442.2	442.7	460.9	4.066	4.049	3.49	14574	14574	14574
PLR099	4.25	4.12	2.95	298.5	299.97	318.02	9.418	9.181	6.96	13460	13460	13460
PLR100	4.31	4.52	4.21	277.8	275.61	278.89	10.148	10.557	9.947	11801	11801	11801
PLR101	4.70	4.82	4.29	243.3	242.45	246.46	10.515	10.756	9.724	10873	10873	10873
PLR102	2.99	2.92	2.02	405.5	407.46	439.09	7.019	6.878	5.122	17287	17287	17287
PLR103	1.01	0.96	0.69	636.5	642.85	687.18	3.651	3.516	2.708	17539	17539	17539
PLR104	2.49	2.46	1.87	398.8	400.04	423.93	6.95	6.87	5.528	14305	14305	14305
PLR105	2.48	2.39	1.64	466.4	470.07	510	6.611	6.421	4.77	17519	17519	17519
PLR106	4.13	4.53	3.54	413.9	406.65	426.53	9.423	10.152	8.331	18130	18130	18130

PLR107	1.54	1.53	1.08	372	372.55	399.65	5.268	5.239	3.971	10881	10881	10881
PLR108	1.71	1.85	1.32	469.7	461.7	495.47	5.714	6.089	4.671	14027	14027	14027
PLR109	2.80	2.81	2.27	301.7	301.6	314.32	7.739	7.751	6.526	10932	10932	10932
PLR110	2.76	2.68	1.95	332.3	334.16	355.42	6.659	6.497	5.025	13763	13763	13763
PLR111	1.61	1.49	1.06	332.1	336.9	361.24	5.166	4.877	3.697	10318	10318	10318

Scenario 4 – Constant urban sprawl

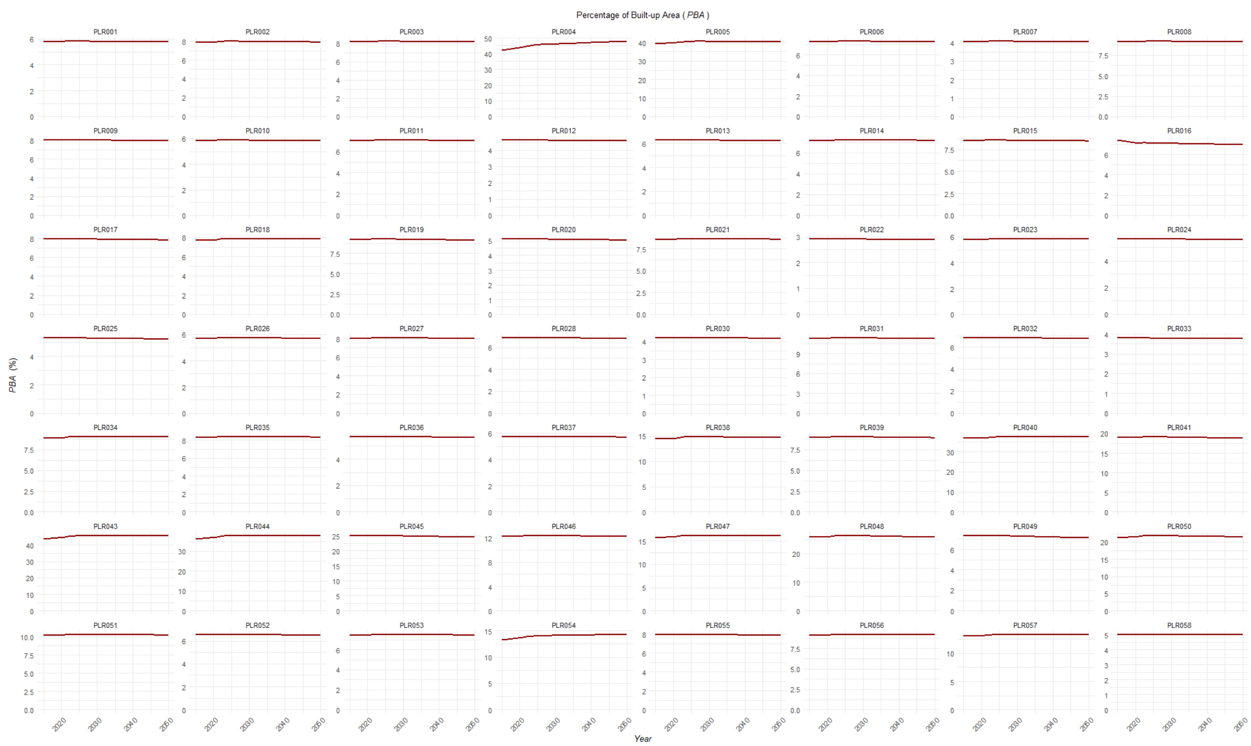

Figure C-21- projected changes in PBA between 2015 – 2050 in scenario 4 (PLR001- PLR058)

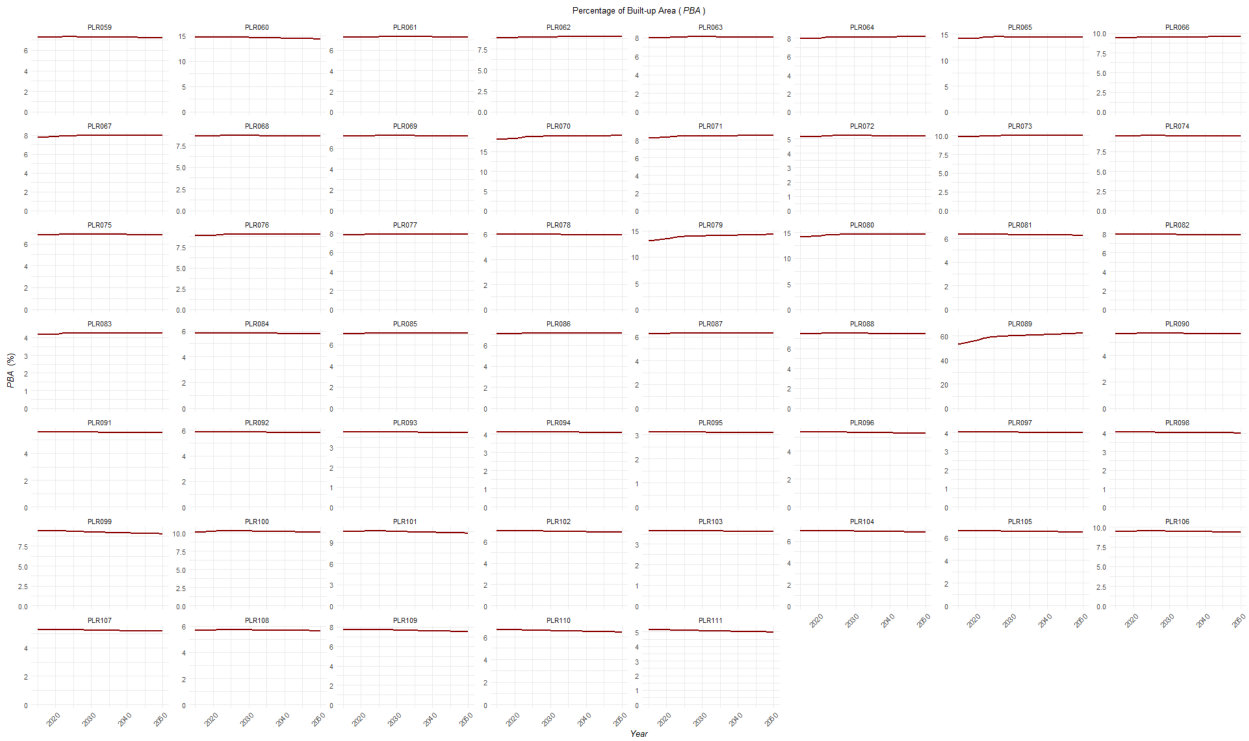

Figure C-22- projected changes in PBA between 2015 – 2050 in scenario 4 (PLR059- PLR111)

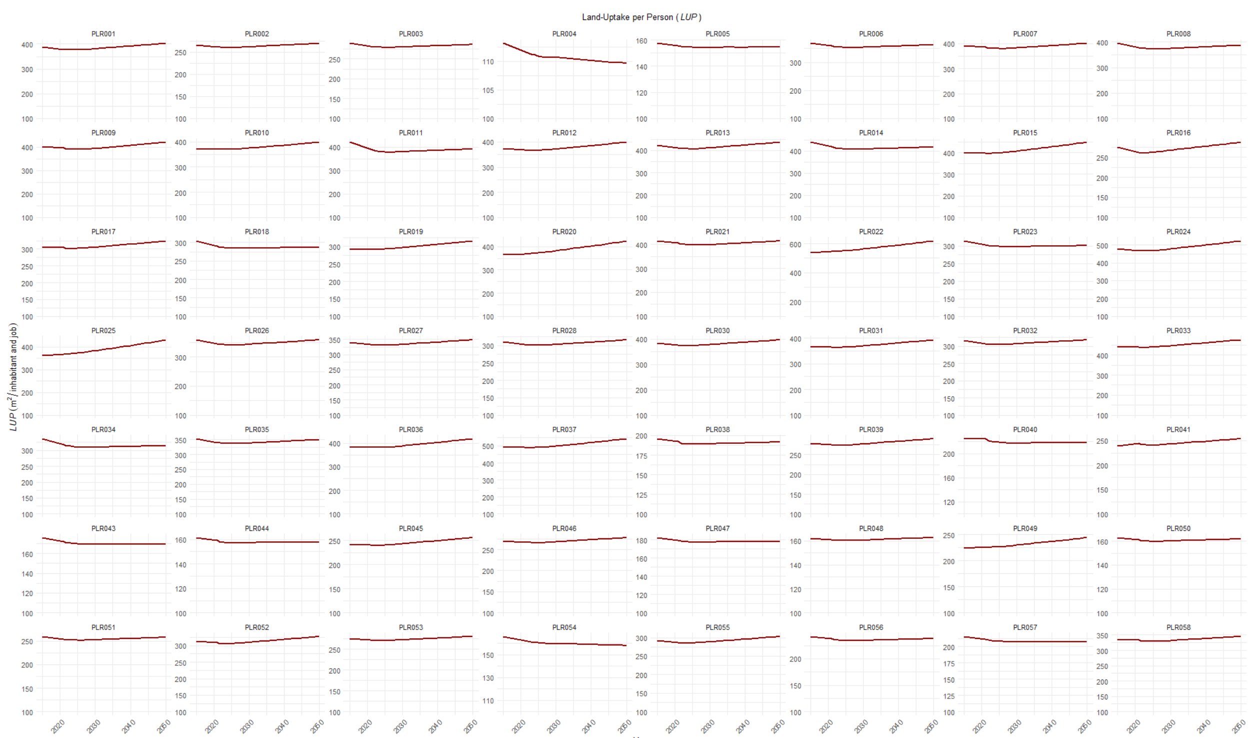

Figure C-23- projected changes in LUP between 2015 – 2050 in scenario 4 (PLR001- PLR058)

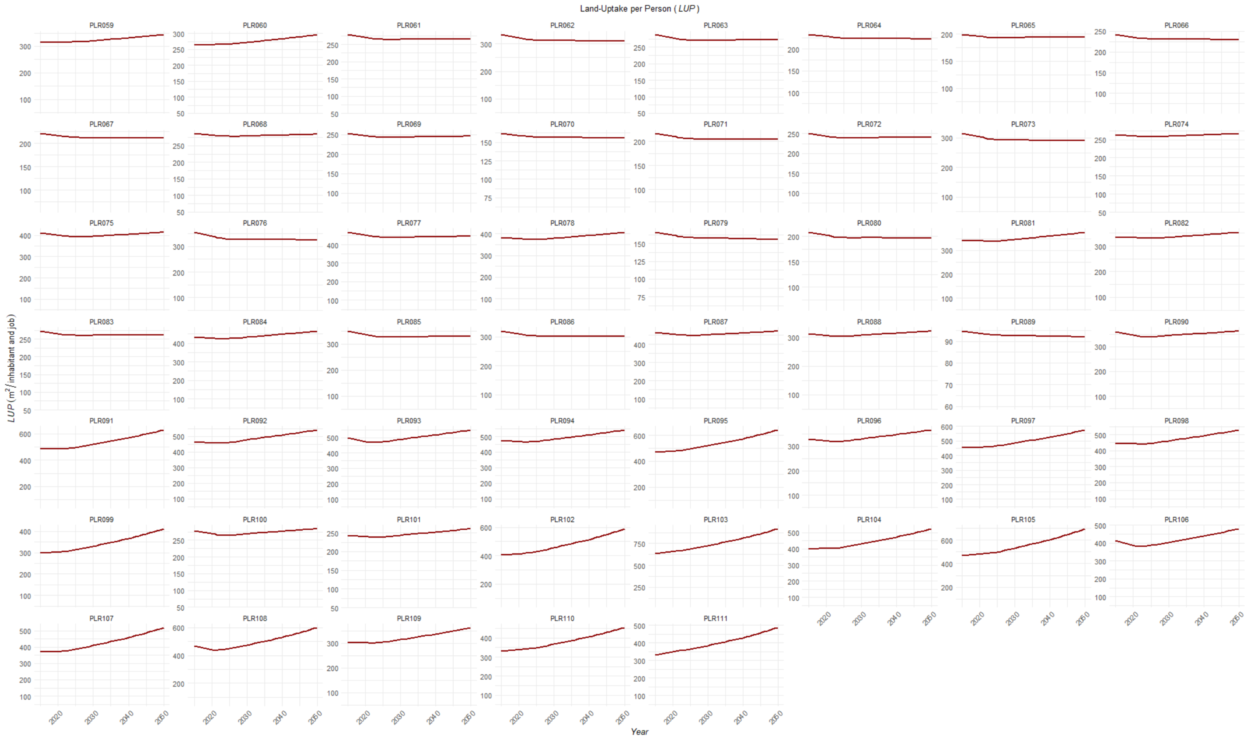

Figure C-24- projected changes in LUP between 2015 – 2050 in scenario 4 (PLR059- PLR111)

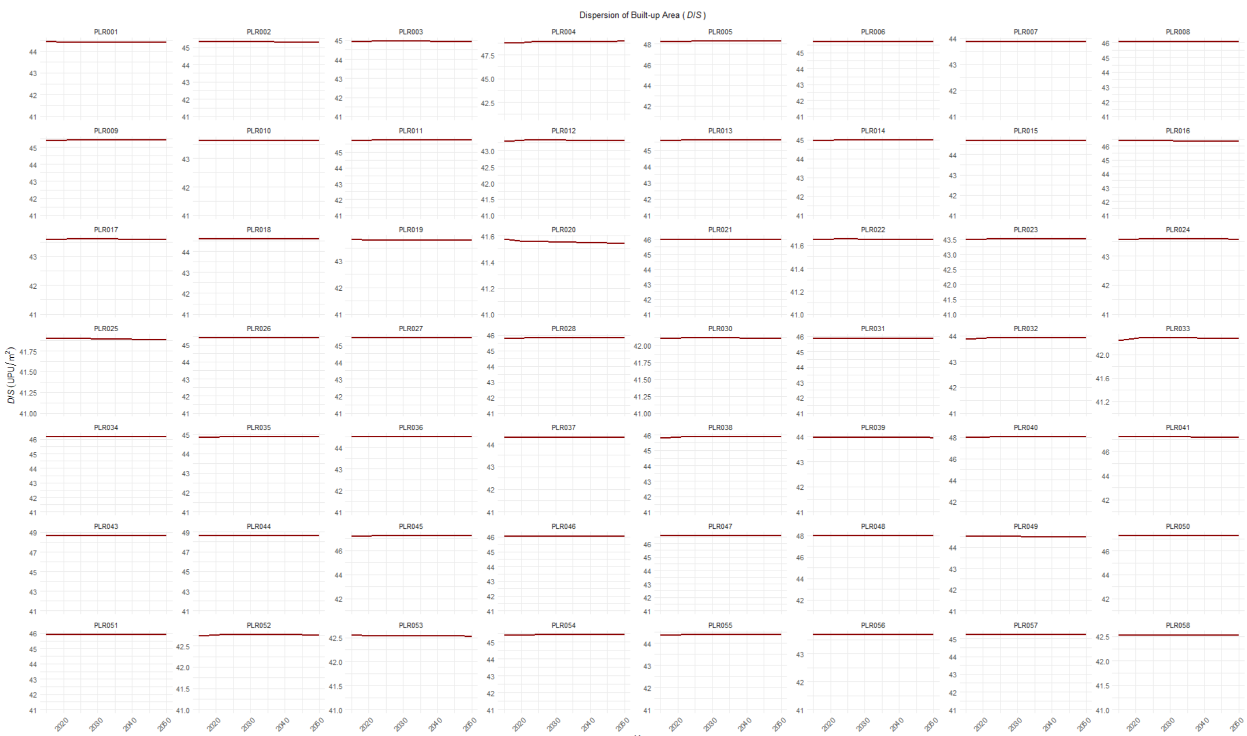

Figure C-25- projected changes in DIS between 2015 – 2050 in scenario 4 (PLR001- PLR058)

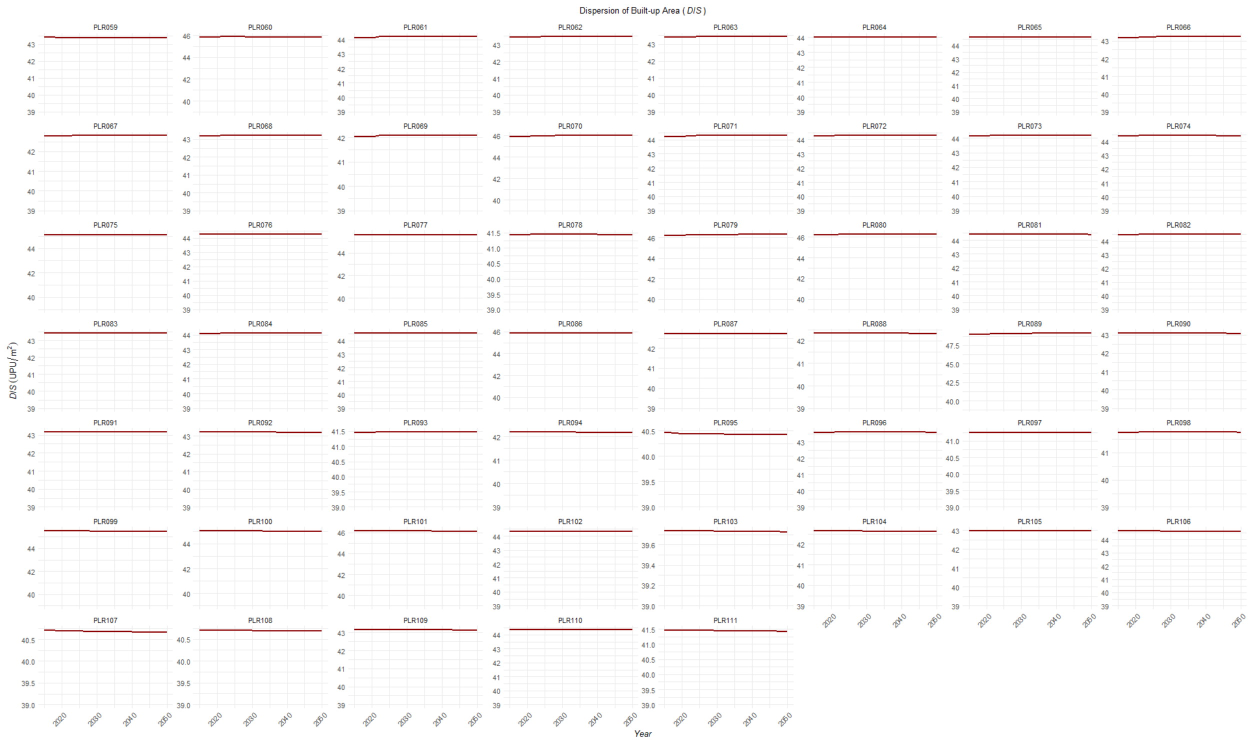

Figure C-26- projected changes in DIS between 2015 – 2050 in scenario 4 (PLR059- PLR111)

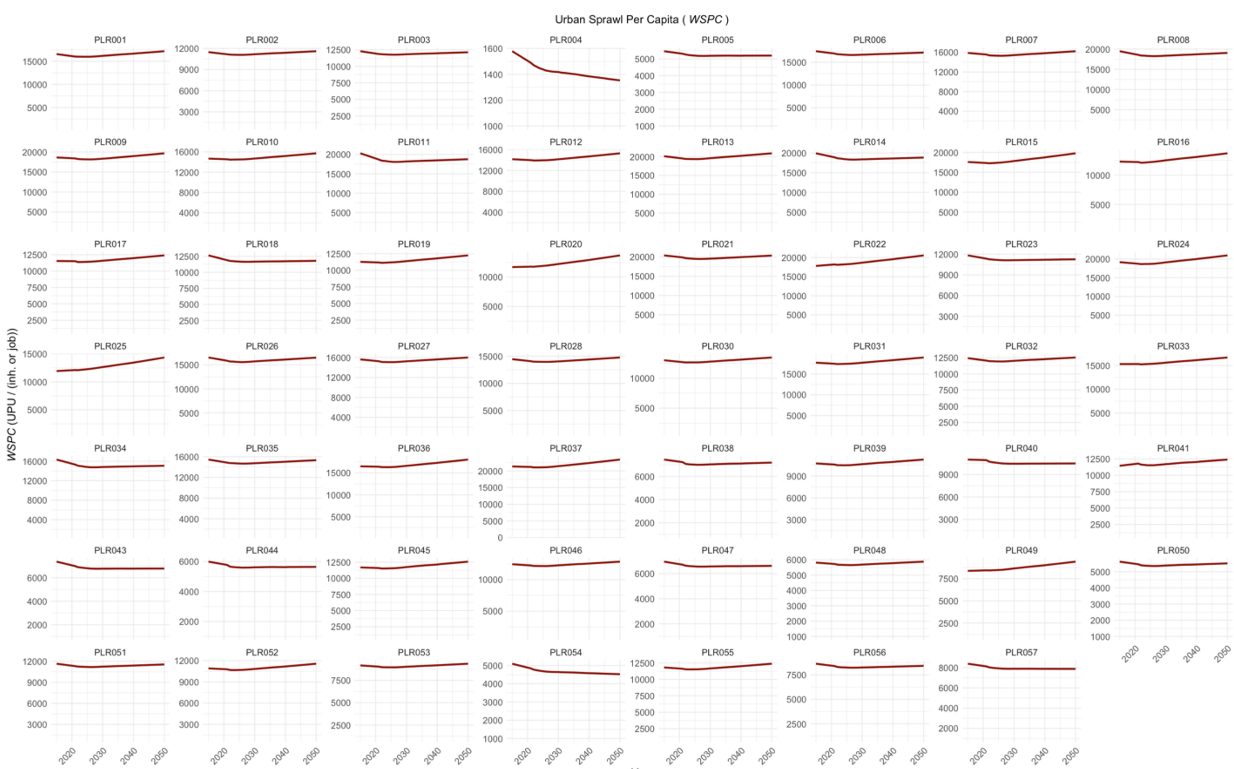

Figure C-27- projected changes in WSPC between 2015 – 2050 in scenario 4 (PLR001- PLR057)

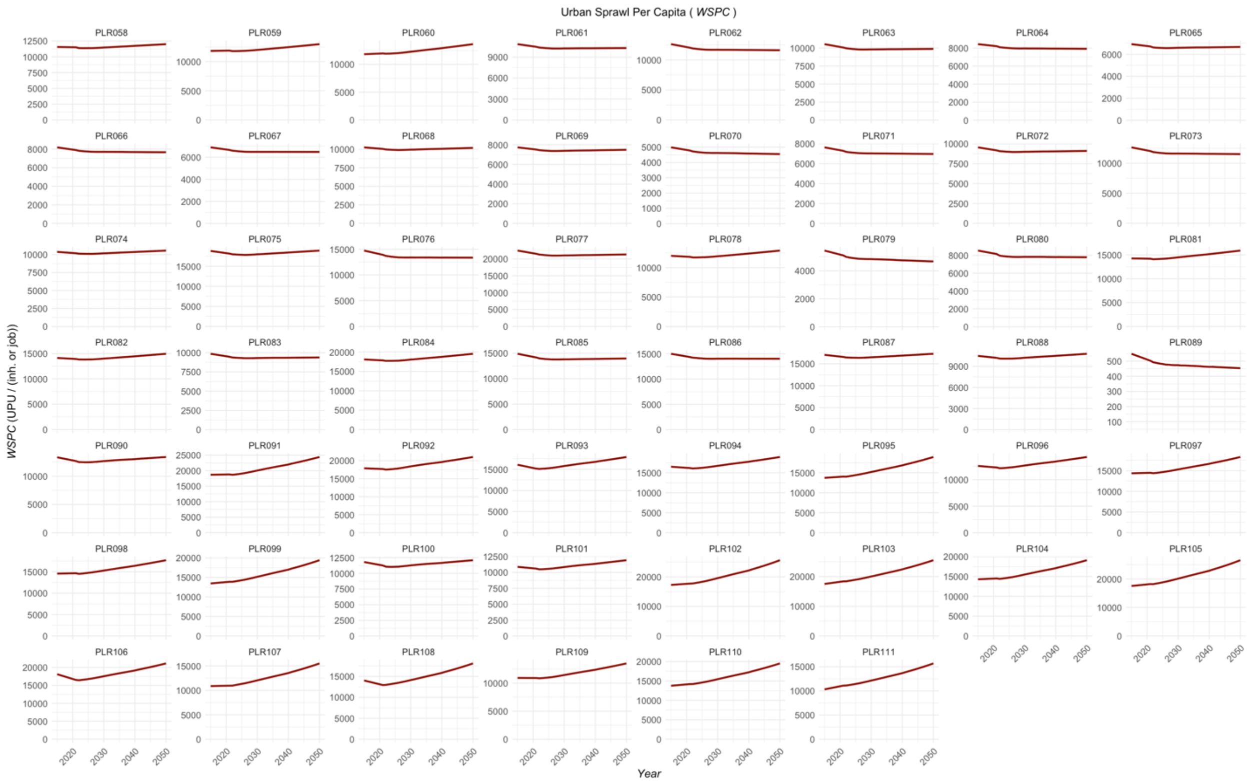

Figure C-28- projected changes in WSPC between 2015 – 2050 in scenario 4 (PLR058- PLR111)

Table C-4- Urban Sprawl Metrics for Scenario 4 in Germany's Planning Regions

	WUP (UPU/m²)			*LUP* (m²/ inh. or job)			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
PLR	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	***2015***	***2021***	***2050***
PLR001	2.47	2.47	2.47	388.1	378	402.8	5.775	5.814	5.777	16567	16028	17191
PLR002	3.40	3.40	3.40	266.6	261.8	269.8	7.886	7.959	7.892	11481	11172	11608
PLR003	3.47	3.47	3.47	289.3	281.1	286.2	8.171	8.223	8.189	12288	11864	12128
PLR004	5.91	5.91	5.91	113.1	111.7	109.6	42.257	44.238	47.811	1579	1490	1353
PLR005	13.65	13.65	13.65	157.4	155.7	154.4	39.368	40.033	40.566	5460	5310	5198
PLR006	3.44	3.44	3.44	367.9	358.7	362.6	7.257	7.289	7.277	17447	16938	17149
PLR007	1.64	1.64	1.64	392.4	385.5	400.8	4.054	4.067	4.051	15880	15550	16231
PLR008	4.50	4.50	4.50	395	378.7	387.6	9.13	9.18	9.157	19485	18581	19063
PLR009	3.73	3.73	3.73	400.1	394.6	420	8.009	8.004	7.964	18648	18404	19685
PLR010	2.31	2.31	2.31	373.2	371	398	5.863	5.879	5.836	14681	14553	15729
PLR011	3.35	3.35	3.35	421.3	390.2	391.9	6.957	7.001	6.998	20298	18683	18771
PLR012	1.75	1.75	1.75	373.2	368.1	399	4.609	4.603	4.564	14167	13992	15297
PLR013	2.98	2.98	2.98	422.6	409.9	436.5	6.264	6.262	6.229	20096	19500	20877
PLR014	3.26	3.26	3.26	439.3	418.6	417.3	7.182	7.211	7.213	19914	18897	18836
PLR015	3.74	3.74	3.74	400.9	396.5	447.7	8.531	8.56	8.473	17596	17347	19787
PLR016	3.52	3.52	3.52	274.1	262.1	287.2	7.416	7.137	6.969	12291	12210	13704
PLR017	2.99	2.99	2.99	305	304.1	323.8	7.91	7.908	7.822	11543	11512	12393

PLR018	3.22	3.22	3.22	303.9	289.2	287.1	7.737	7.821	7.833	12638	11896	11792
PLR019	3.54	3.54	3.54	293.4	292.1	315.4	9.214	9.256	9.122	11272	11172	12239
PLR020	1.63	1.63	1.63	367.2	369.9	424.3	5.116	5.12	5.053	11680	11756	13665
PLR021	4.24	4.24	4.24	413.7	404.9	413.9	8.588	8.627	8.609	20409	19884	20368
PLR022	0.96	0.96	0.96	538.3	549.1	617.9	2.909	2.904	2.891	17825	18210	20588
PLR023	2.18	2.18	2.18	313.6	302.6	300.5	5.782	5.811	5.819	11826	11355	11260
PLR024	2.25	2.25	2.25	480.1	469.2	521.9	5.644	5.641	5.607	19154	18726	20959
PLR025	1.74	1.74	1.74	362.9	368.1	429.9	5.304	5.299	5.222	11927	12110	14352
PLR026	2.63	2.63	2.63	359	346.5	359	5.702	5.735	5.712	16541	15870	16513
PLR027	3.67	3.67	3.67	340.8	334.3	348.6	8.021	8.053	8.005	15613	15251	16003
PLR028	3.18	3.18	3.18	311.1	303.8	316.2	6.84	6.855	6.805	14454	14081	14765
PLR030	1.42	1.42	1.42	383.9	375.9	396.5	4.198	4.209	4.186	12973	12670	13436
PLR031	5.46	5.46	5.46	368.4	364.7	392.9	11.338	11.391	11.298	17736	17475	18980
PLR032	2.67	2.67	2.67	316.9	307.7	318.1	6.806	6.812	6.772	12415	12044	12524
PLR033	1.32	1.32	1.32	440.4	439.1	475.8	3.81	3.796	3.775	15291	15303	16672
PLR034	4.34	4.34	4.34	336.1	318.5	314.2	8.922	9.015	9.037	16338	15324	15078
PLR035	3.65	3.65	3.65	353.1	340.8	350.1	8.347	8.374	8.342	15445	14862	15326
PLR036	2.44	2.44	2.44	385.2	383.6	418.3	5.696	5.701	5.655	16496	16415	18042
PLR037	2.46	2.46	2.46	495.3	493.1	541.8	5.713	5.727	5.699	21319	21174	23379
PLR038	5.51	5.51	5.51	195.8	192.1	191.5	14.458	14.62	14.658	7460	7240	7198
PLR039	3.46	3.46	3.46	278.6	276	290.3	8.986	9.033	8.927	10730	10574	11254
PLR040	18.08	18.08	18.08	224.3	223.7	217.7	36.831	36.978	37.501	11012	10938	10496
PLR041	9.18	9.18	9.18	239.2	244.4	253.7	19.171	19.034	18.787	11457	11790	12399
PLR043	18.27	18.27	18.27	176	171.9	169.6	43.683	44.96	45.72	7364	6989	6779
PLR044	13.47	13.47	13.47	161.5	159.2	157.7	36.302	37.112	37.638	5992	5777	5645
PLR045	12.05	12.05	12.05	242.7	240.9	255.9	25.041	25.057	24.525	11680	11584	12573
PLR046	5.67	5.67	5.67	270.4	267.8	278.1	12.313	12.388	12.265	12448	12253	12851
PLR047	5.96	5.96	5.96	182.6	179.7	178.4	15.677	15.975	16.086	6940	6701	6609
PLR048	9.30	9.30	9.30	162	161	162.7	25.894	26.128	25.735	5816	5729	5878
PLR049	2.74	2.74	2.74	224.2	225.9	244.1	7.346	7.345	7.116	8372	8435	9410
PLR050	7.34	7.34	7.34	162.9	161.1	161.7	21.278	21.65	21.527	5619	5460	5513
PLR051	4.57	4.57	4.57	259.9	254.1	258.1	10.211	10.279	10.228	11640	11306	11541
PLR052	2.29	2.29	2.29	312.5	308.8	327.8	6.561	6.559	6.493	10915	10789	11569
PLR053	2.49	2.49	2.49	275.4	272.8	280.6	7.484	7.526	7.475	9173	9037	9358
PLR054	4.10	4.10	4.10	166.1	162.7	158.2	13.36	13.765	14.331	5096	4845	4524
PLR055	3.21	3.21	3.21	292.5	287.7	303.2	7.941	7.946	7.86	11824	11623	12383
PLR056	3.24	3.24	3.24	242.1	237.7	238	9.088	9.165	9.16	8634	8405	8424
PLR057	5.08	5.08	5.08	215.7	211.6	207.5	13.063	13.217	13.373	8384	8129	7878
PLR058	1.74	1.74	1.74	333.6	333	345.3	5.011	5.021	4.994	11559	11514	12005
PLR059	2.73	2.73	2.73	315.3	317.7	343.1	7.268	7.289	7.203	11841	11897	13002
PLR060	6.64	6.64	6.64	263.9	266.1	295.6	14.8	14.749	14.377	11834	11976	13643
PLR061	2.81	2.81	2.81	277.8	269.2	265.6	7.199	7.228	7.254	10840	10461	10285
PLR062	3.35	3.35	3.35	332.6	319.5	309.9	8.841	8.906	8.952	12619	12033	11612
PLR063	2.93	2.93	2.93	287.6	276.9	272.6	7.997	8.054	8.086	10533	10069	9876

PLR064	2.89	2.89	2.89	232.5	228.7	223.1	7.964	8.052	8.142	8433	8206	7916
PLR065	4.94	4.94	4.94	198.6	195.5	194.7	14.158	14.36	14.406	6922	6718	6668
PLR066	3.18	3.18	3.18	241.4	234.8	229.9	9.385	9.463	9.548	8179	7891	7657
PLR067	2.43	2.43	2.43	221.1	216	212.2	7.804	7.888	7.967	6888	6658	6476
PLR068	3.07	3.07	3.07	286.6	281.5	284.5	8.564	8.583	8.562	10264	10058	10192
PLR069	2.19	2.19	2.19	252.4	246.3	245.6	7.133	7.163	7.17	7733	7514	7487
PLR070	5.56	5.56	5.56	161.8	158.9	155.8	18.035	18.464	19.04	4986	4784	4547
PLR071	2.91	2.91	2.91	215.8	209.1	203.4	8.227	8.349	8.494	7641	7295	6976
PLR072	1.96	1.96	1.96	250.3	242.8	241.5	5.138	5.191	5.201	9555	9177	9110
PLR073	3.96	3.96	3.96	314.7	301.3	290.6	9.855	9.914	9.988	12655	12046	11529
PLR074	3.73	3.73	3.73	263.8	259.3	266.5	9.475	9.485	9.41	10371	10185	10551
PLR075	3.11	3.11	3.11	411.7	399.3	414.3	6.807	6.842	6.819	18821	18158	18907
PLR076	3.68	3.68	3.68	355.8	338.4	326.5	8.893	8.956	9.004	14738	13921	13360
PLR077	3.77	3.77	3.77	466.4	449.2	445.5	7.833	7.878	7.883	22470	21518	21330
PLR078	1.88	1.88	1.88	381.1	375.3	406	5.983	5.983	5.937	12002	11821	12889
PLR079	4.29	4.29	4.29	165.7	161.3	155.7	13.067	13.568	14.311	5437	5096	4664
PLR080	5.81	5.81	5.81	207.7	201.8	196.5	14.123	14.369	14.648	8542	8158	7791
PLR081	2.64	2.64	2.64	341.1	339.5	375.7	6.326	6.324	6.249	14261	14199	15903
PLR082	3.32	3.32	3.32	336.6	331.9	353	7.91	7.913	7.845	14132	13929	14945
PLR083	1.52	1.52	1.52	272.2	264	261.9	4.199	4.235	4.245	9848	9469	9374
PLR084	2.43	2.43	2.43	433.7	427.4	465.1	5.829	5.824	5.786	18091	17843	19544
PLR085	2.99	2.99	2.99	350	335.2	331	7.025	7.067	7.08	14881	14166	13962
PLR086	3.32	3.32	3.32	319.4	308.1	301.8	7.065	7.113	7.141	15010	14382	14031
PLR087	2.30	2.30	2.30	464.1	453.4	471.6	6.275	6.304	6.287	17028	16562	17270
PLR088	2.52	2.52	2.52	312.8	306	320.6	7.498	7.536	7.475	10494	10214	10788
PLR089	3.05	3.05	3.05	94.7	93.5	92.1	52.893	56.931	62.224	548	503	453
PLR090	2.09	2.09	2.09	359.8	344.5	361.7	5.633	5.671	5.64	13330	12678	13383
PLR091	2.15	2.15	2.15	486.2	489	628	5.6	5.599	5.536	18684	18794	24410
PLR092	2.25	2.25	2.25	464.4	459.9	541.6	5.84	5.852	5.799	17911	17700	21034
PLR093	1.22	1.22	1.22	497.5	469.9	550.2	3.767	3.773	3.741	16068	15154	17895
PLR094	1.43	1.43	1.43	475.4	467	542	4.107	4.116	4.082	16522	16195	18949
PLR095	0.91	0.91	0.91	470.5	482	642	3.115	3.12	3.08	13720	14033	18932
PLR096	2.05	2.05	2.05	327.7	320.7	365.5	5.341	5.35	5.257	12575	12285	14251
PLR097	1.27	1.27	1.27	455.8	460.1	574.4	4.033	4.037	3.991	14371	14492	18302
PLR098	1.34	1.34	1.34	442.2	443	529.3	4.066	4.051	4.009	14574	14652	17696
PLR099	4.25	4.25	4.25	298.5	306.6	412.7	9.418	9.384	9.031	13460	13875	19405
PLR100	4.31	4.31	4.31	277.8	268.3	284.1	10.148	10.278	10.131	11801	11255	12087
PLR101	4.70	4.70	4.70	243.3	239.2	261	10.515	10.611	10.296	10873	10592	11910
PLR102	2.99	2.99	2.99	405.5	416.2	590.1	7.019	7.026	6.884	17287	17726	25649
PLR103	1.01	1.01	1.01	636.5	666.4	918.1	3.651	3.645	3.618	17539	18393	25529
PLR104	2.49	2.49	2.49	398.8	404.8	523.8	6.95	6.951	6.831	14305	14517	19116
PLR105	2.48	2.48	2.48	466.4	482.8	694.5	6.611	6.595	6.495	17519	18179	26553
PLR106	4.13	4.13	4.13	413.9	381.8	479.1	9.423	9.532	9.358	18130	16534	21131
PLR107	1.54	1.54	1.54	372	375.6	519.1	5.268	5.282	5.157	10881	10957	15510

PLR108	1.71	1.71	1.71	469.7	436.4	600.1	5.714	5.755	5.657	14027	12939	18101
PLR109	2.80	2.80	2.80	301.7	301.3	362.7	7.739	7.742	7.53	10932	10911	13506
PLR110	2.76	2.76	2.76	332.3	340.4	455	6.659	6.618	6.433	13763	14186	19506
PLR111	1.61	1.61	1.61	332.1	354.5	487.4	5.166	5.131	4.988	10318	11089	15684

Scenario 5A- Densification in growing regions

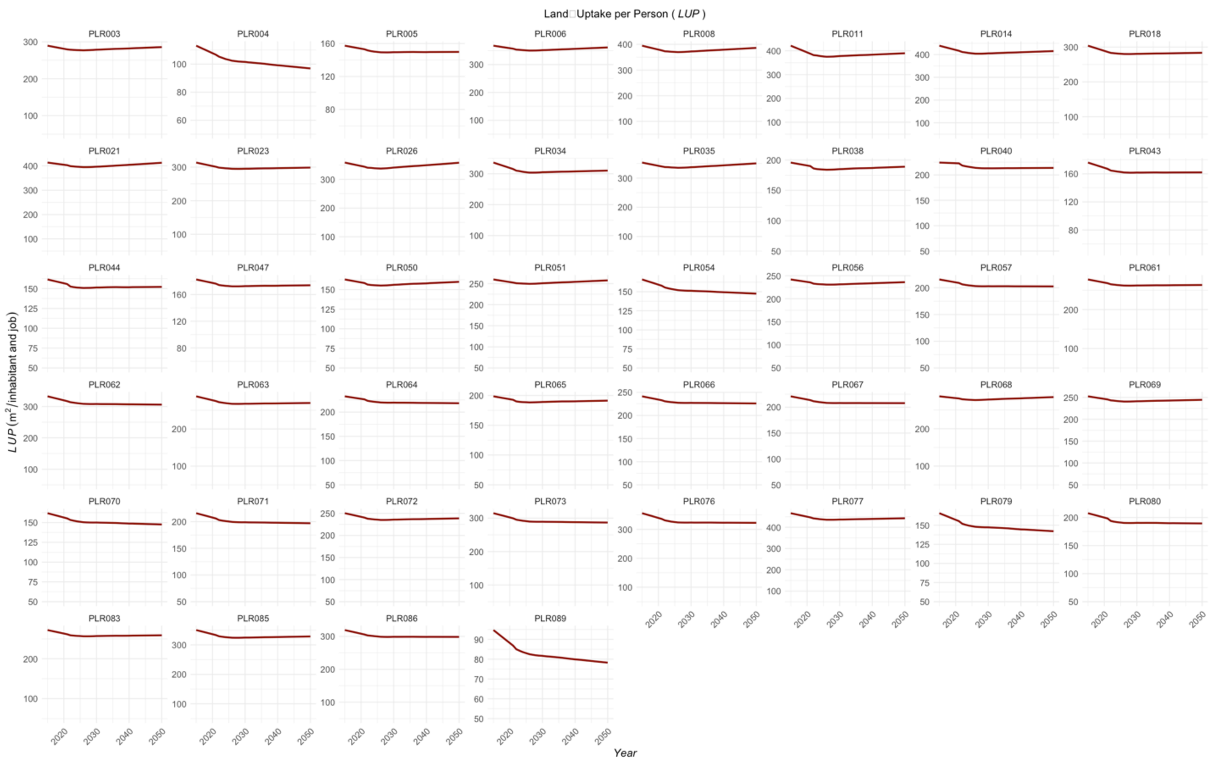

Figure C-29- projected changes in LUP between 2015 – 2050 in scenario 5A in PLRs with population increase

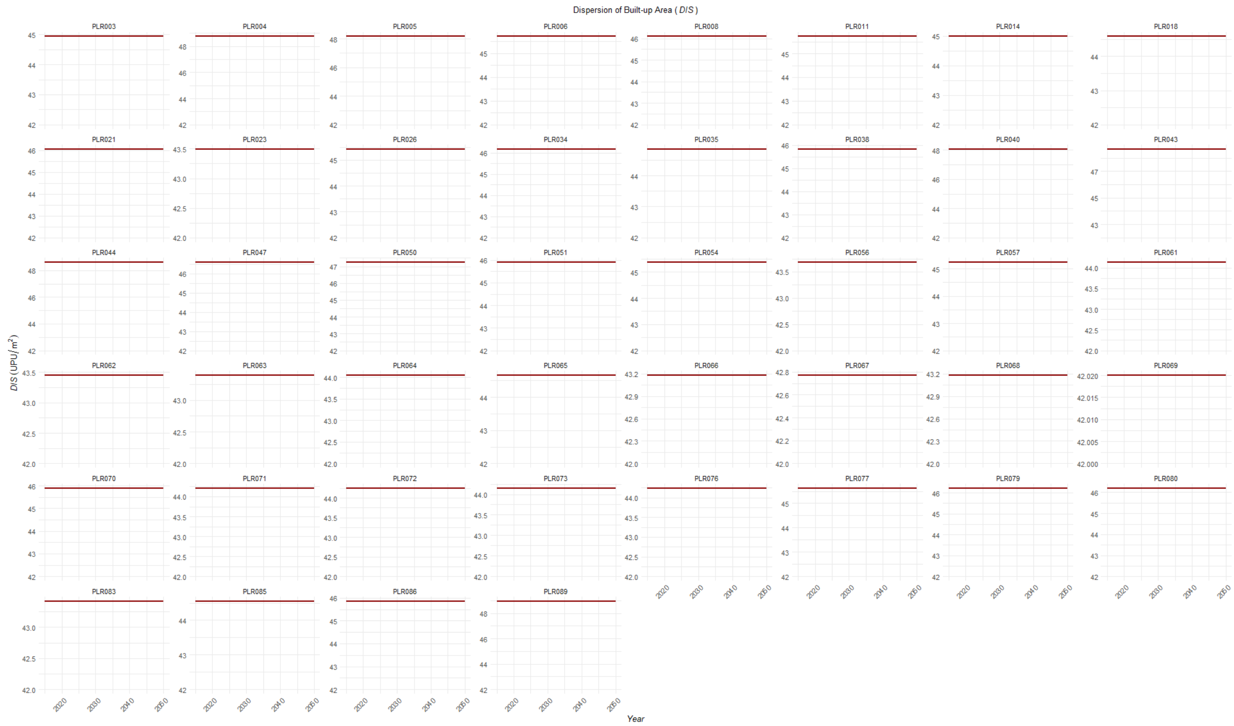

Figure C-30- projected changes in DIS between 2015 – 2050 in scenario 5A in PLRs with population increase

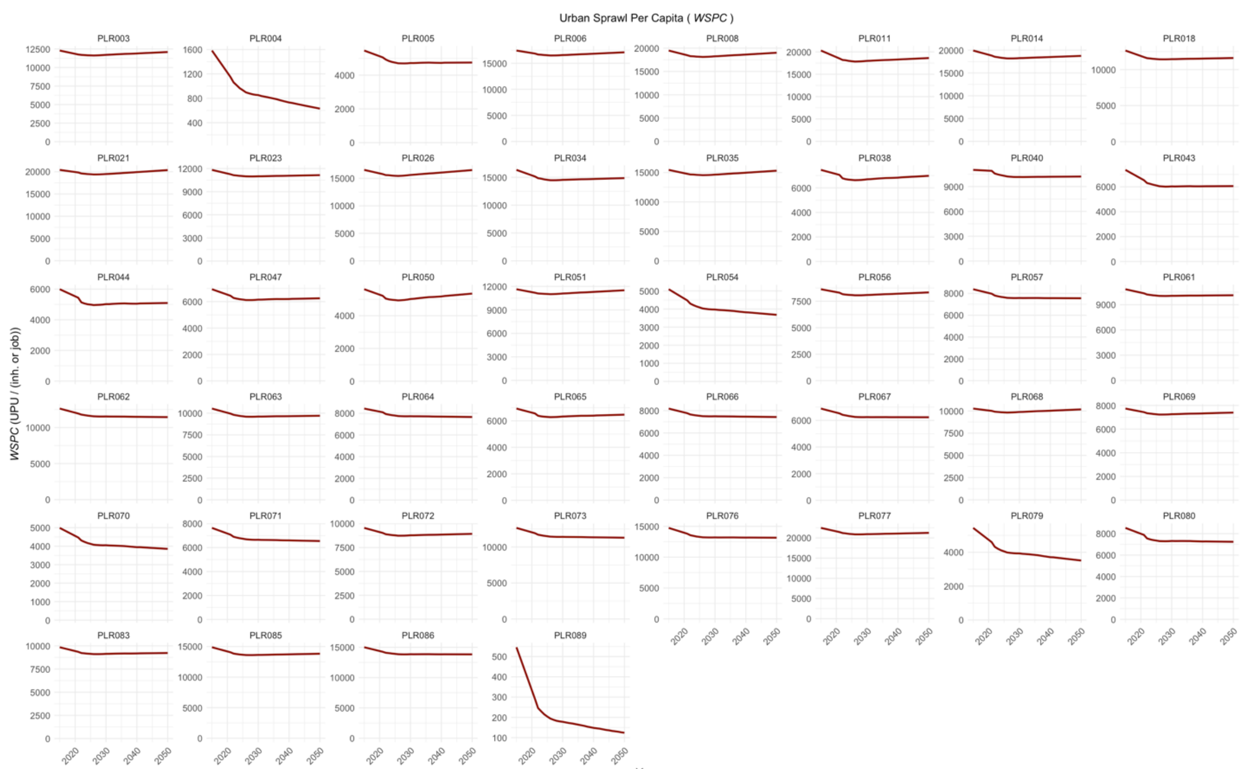

Figure C-31- projected changes in WSPC between 2015 – 2050 in scenario 5A in PLRs with population increase

Table C-5- Urban Sprawl Metrics for Scenario 5A

	WUP (UPU/ m^2)			*LUP* (m^2/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ inh. or job)		
PLR	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	***2015***	***2021***	***2050***
PLR003	3.471	3.44	3.459	289.3	279.31	285.53	8.17	8.17	8.17	12288	11757	12089
PLR004	5.913	4.551	2.749	113.1	106.7	96.89	42.26	42.26	42.26	1583	1149	630
PLR005	13.649	12.992	12.474	157.4	153.07	149.85	39.37	39.37	39.37	5457	5052	4748
PLR006	3.441	3.428	3.433	367.9	357.17	361.63	7.26	7.26	7.26	17446	16871	17110
PLR008	4.504	4.48	4.493	395	376.67	386.45	9.13	9.13	9.13	19485	18481	19018
PLR011	3.352	3.324	3.325	421.3	387.77	389.59	6.96	6.96	6.96	20297	18526	18622
PLR014	3.255	3.24	3.239	439.3	416.88	415.53	7.18	7.18	7.18	19913	18810	18743
PLR018	3.218	3.173	3.166	303.9	286.08	283.57	7.74	7.74	7.74	12640	11733	11605
PLR021	4.237	4.226	4.236	413.7	403.06	412.87	8.59	8.59	8.59	20412	19836	20367
PLR023	2.181	2.163	2.159	313.6	301.11	298.6	5.78	5.78	5.78	11828	11262	11148
PLR026	2.627	2.612	2.627	359	344.44	358.4	5.7	5.7	5.7	16541	15776	16510
PLR034	4.337	4.288	4.275	336.1	315.23	310.18	8.92	8.92	8.92	16338	15152	14862
PLR035	3.652	3.631	3.647	353.1	339.78	350.37	8.35	8.35	8.35	15446	14778	15310
PLR038	5.511	5.369	5.341	195.8	190.02	188.92	14.46	14.46	14.46	7463	7057	6979
PLR040	18.083	18.019	17.593	224.3	222.81	213.8	36.83	36.83	36.83	11013	10900	10213
PLR043	18.266	17.084	16.334	176	167.05	162.02	43.68	43.68	43.68	7360	6533	6058
PLR044	13.467	12.677	12.154	161.5	155.7	152.13	36.3	36.3	36.3	5991	5437	5093
PLR047	5.959	5.733	5.639	182.6	176.3	173.88	15.68	15.68	15.68	6941	6448	6255
PLR050	7.337	7.011	7.123	162.9	158.3	159.84	21.28	21.28	21.28	5617	5216	5350
PLR051	4.572	4.526	4.559	259.9	252.45	257.69	10.21	10.21	10.21	11637	11189	11505
PLR054	4.097	3.789	3.334	166.1	157.9	147.46	13.36	13.36	13.36	5094	4478	3680
PLR056	3.241	3.203	3.206	242.1	235.66	236.19	9.09	9.09	9.09	8633	8306	8333
PLR057	5.078	4.98	4.872	215.7	209.14	202.67	13.06	13.06	13.06	8385	7973	7558
PLR061	2.809	2.781	2.766	277.8	268.09	263.58	7.2	7.2	7.2	10842	10356	10127
PLR062	3.355	3.327	3.303	332.6	317.15	306.06	8.84	8.84	8.84	12620	11933	11435
PLR063	2.929	2.895	2.878	287.6	274.94	269.66	8	8	8	10534	9951	9705
PLR064	2.889	2.85	2.795	232.5	226.22	218.23	7.96	7.96	7.96	8435	8097	7659
PLR065	4.937	4.816	4.784	198.6	192.75	191.32	14.16	14.16	14.16	6925	6557	6465
PLR066	3.181	3.13	3.084	241.4	232.9	225.98	9.39	9.39	9.39	8181	7768	7426
PLR067	2.432	2.384	2.341	221.1	213.72	207.88	7.8	7.8	7.8	6889	6528	6236
PLR068	3.067	3.051	3.062	286.6	280.86	284.59	8.56	8.56	8.56	10264	10006	10174
PLR069	2.186	2.162	2.159	252.4	245.24	244.36	7.13	7.13	7.13	7735	7434	7396
PLR070	5.557	5.19	4.709	161.8	155.25	147.57	18.03	18.03	18.03	4986	4468	3853
PLR071	2.913	2.827	2.733	215.8	206.02	197.01	8.23	8.23	8.23	7640	7078	6545
PLR072	1.961	1.93	1.924	250.3	240.38	238.63	5.14	5.14	5.14	9554	9028	8934
PLR073	3.963	3.923	3.882	314.7	299.54	286.7	9.85	9.85	9.85	12655	11923	11295
PLR076	3.683	3.652	3.626	355.8	336.08	322.54	8.89	8.89	8.89	14735	13801	13152
PLR077	3.774	3.761	3.759	466.4	446.63	442.72	7.83	7.83	7.83	22470	21447	21244
PLR079	4.286	3.865	3.227	165.7	155.31	142.13	13.07	13.07	13.07	5435	4594	3510

PLR080	5.808	5.615	5.399	207.7	198.38	189.46	14.12	14.12	14.12	8541	7887	7243
PLR083	1.519	1.501	1.496	272.2	261.72	259.09	4.2	4.2	4.2	9847	9353	9229
PLR085	2.987	2.964	2.957	350	333.2	328.39	7.02	7.02	7.02	14880	14058	13822
PLR086	3.32	3.292	3.275	319.4	306.03	298.56	7.06	7.06	7.06	15009	14261	13839
PLR089	3.051	1.773	0.839	94.7	86.87	78.25	52.89	52.89	52.89	546	291	124

Scenario 5B- Densification in shrinking regions

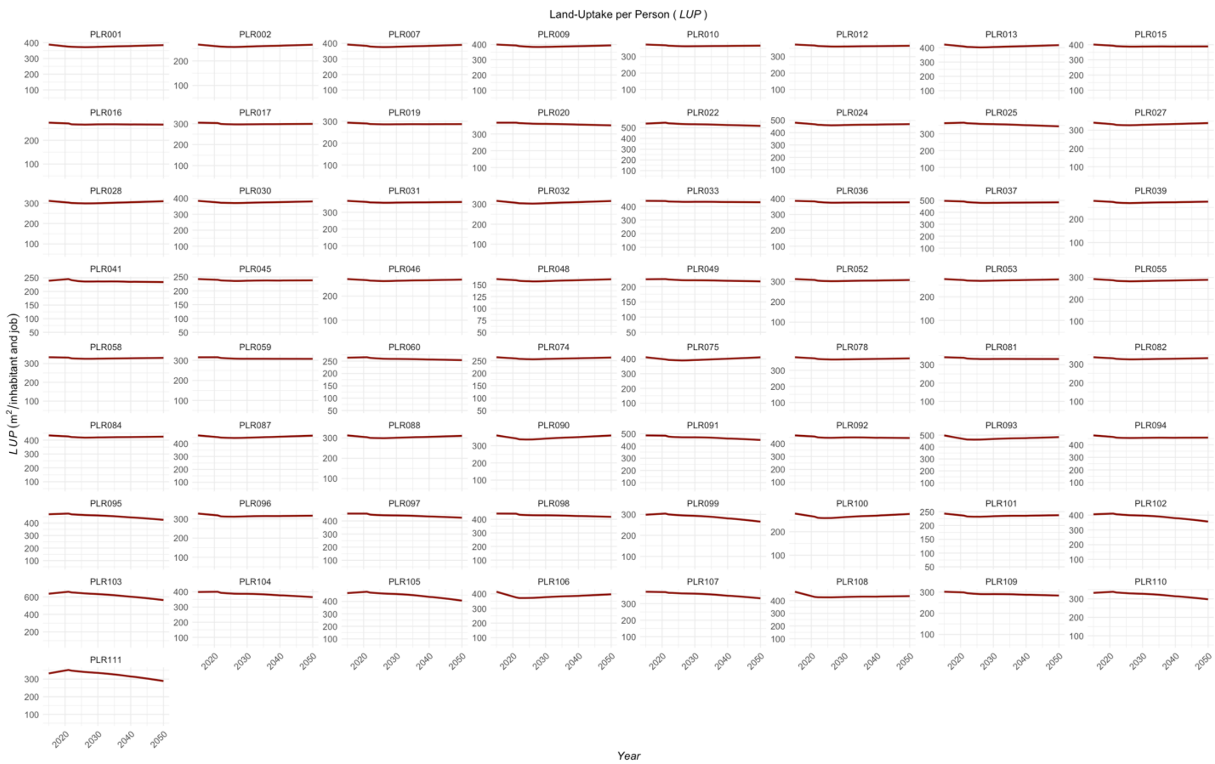

Figure C-32- projected changes in LUP between 2015 – 2050 in scenario 5B in PLRs with population decrease

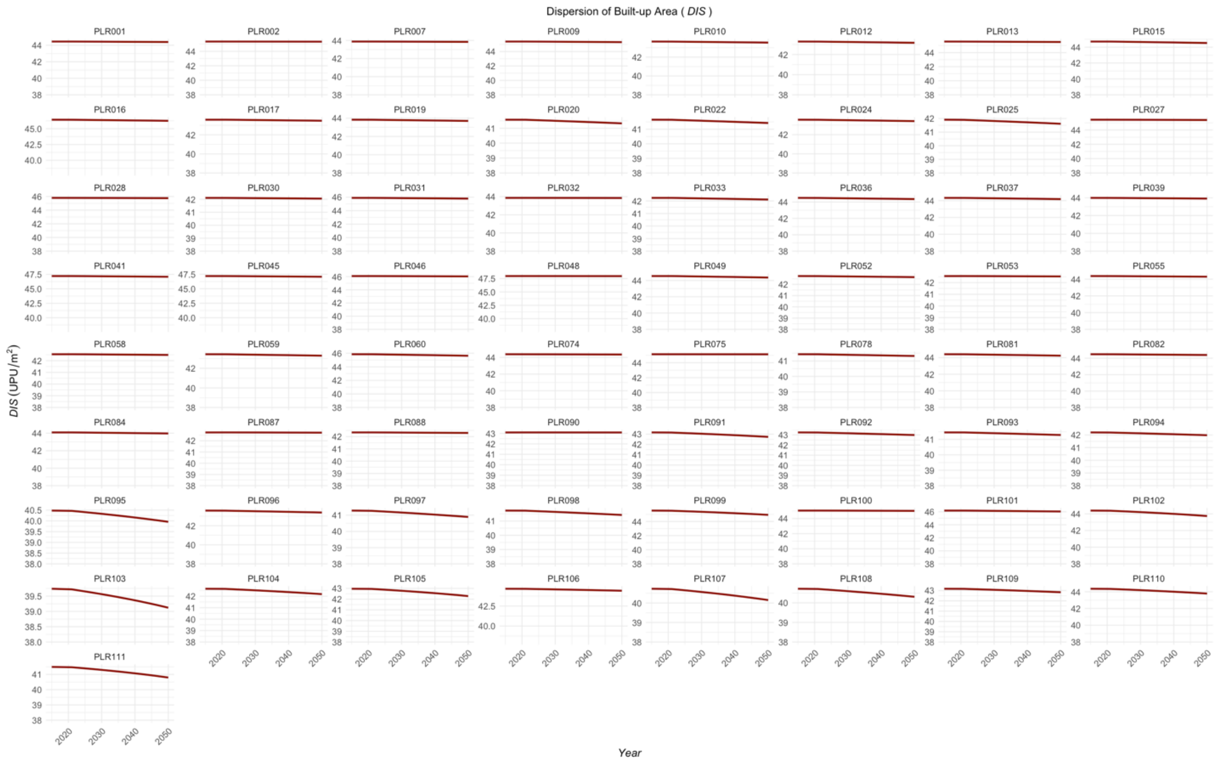

Figure C-33- projected changes in DIS between 2015 – 2050 in scenario 5B in PLRs with population decrease

Figure C-34- projected changes in WSPC between 2015 – 2050 in scenario 5B in PLRs with population decrease

Table C-6- Urban Sprawl Metrics for Scenario 5B

	WUP (UPU/m^2)			*LUP* (m2/ (inh. or job))			*PBA* (%)			*WSPC* (UPU/ (inh. or job))		
PLR	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**	**2015**	**2021**	**2050**
PLR001	2.465	2.451	2.338	388.1	374.9	384.4	5.78	5.767	5.513	16568	15938	16306
PLR002	3.395	3.363	3.341	266.6	259.3	265.9	7.89	7.883	7.778	11478	11064	11420
PLR007	1.641	1.635	1.590	392.4	383.9	390.2	4.05	4.051	3.945	15881	15498	15732
PLR009	3.733	3.718	3.457	400.1	394.0	394.5	8.01	7.992	7.482	18651	18332	18230
PLR010	2.306	2.296	2.087	373.2	368.9	366.5	5.86	5.847	5.375	14679	14485	14232
PLR012	1.749	1.740	1.565	373.2	367.4	365.8	4.61	4.595	4.183	14165	13914	13682
PLR013	2.979	2.965	2.823	422.6	409.4	418.5	6.26	6.254	5.971	20096	19409	19783
PLR015	3.744	3.717	3.161	400.9	393.4	388.4	8.53	8.492	7.351	17594	17221	16701
PLR016	3.516	3.488	2.996	274.1	271.1	266.2	7.42	7.384	6.460	12994	12808	12346
PLR017	2.993	2.980	2.696	305	303.3	299.4	7.91	7.888	7.232	11541	11460	11160
PLR019	3.540	3.517	3.134	293.4	289.8	287.1	9.21	9.183	8.304	11273	11098	10836
PLR020	1.628	1.617	1.291	367.2	367.3	351.6	5.12	5.085	4.187	11682	11677	10841
PLR022	0.963	0.958	0.781	538.3	546.8	517.4	2.91	2.892	2.421	17824	18109	16701
PLR024	2.252	2.239	1.978	480.1	467.7	468.8	5.64	5.624	5.036	19155	18618	18412
PLR025	1.743	1.731	1.324	362.9	365.9	344.5	5.3	5.267	4.184	11927	12027	10904
PLR027	3.675	3.656	3.547	340.8	332.6	338.7	8.02	8.013	7.777	15613	15175	15449
PLR028	3.178	3.158	3.083	311.1	302.8	309.4	6.84	6.834	6.659	14456	13991	14323
PLR030	1.419	1.412	1.349	383.9	374.4	380.5	4.2	4.192	4.017	12973	12613	12772
PLR031	5.459	5.431	4.957	368.4	362.0	361.9	11.34	11.307	10.409	17739	17385	17237
PLR032	2.666	2.649	2.633	316.9	307.3	316.2	6.81	6.803	6.732	12416	11967	12367
PLR033	1.323	1.317	1.167	440.4	439.2	430.5	3.81	3.797	3.415	15291	15240	14711
PLR036	2.440	2.428	2.144	385.2	381.9	376.2	5.7	5.676	5.086	16498	16335	15857
PLR037	2.459	2.448	2.155	495.3	490.1	483.3	5.71	5.693	5.084	21320	21074	20489
PLR039	3.461	3.438	3.225	278.6	274.0	275.2	8.99	8.969	8.462	10730	10503	10487
PLR041	9.184	9.249	8.164	239.2	245.4	234.3	19.17	19.111	17.352	11458	11876	11023
PLR045	12.050	11.955	10.802	242.7	240.0	238.1	25.04	24.967	22.818	11679	11491	11269
PLR046	5.669	5.631	5.412	270.4	265.8	268.2	12.31	12.297	11.831	12449	12173	12269
PLR048	9.297	9.069	9.124	162	159.5	161.6	25.89	25.883	25.548	5816	5590	5770
PLR049	2.743	2.733	2.284	224.2	224.9	217.2	7.35	7.313	6.333	8372	8405	7835
PLR052	2.291	2.279	2.103	312.5	308.2	307.8	6.56	6.545	6.097	10914	10730	10619
PLR053	2.493	2.479	2.420	275.4	271.1	274.0	7.48	7.478	7.299	9174	8988	9086
PLR055	3.210	3.189	3.000	292.5	287.0	289.0	7.94	7.926	7.493	11825	11546	11573
PLR058	1.736	1.732	1.643	333.6	331.8	330.4	5.01	5.003	4.778	11560	11485	11361
PLR059	2.730	2.719	2.378	315.3	315.6	307.6	7.27	7.241	6.457	11841	11850	11327
PLR060	6.637	6.610	5.363	263.9	265.6	253.8	14.8	14.718	12.346	11834	11927	11024
PLR074	3.726	3.700	3.632	263.8	258.9	262.7	9.48	9.469	9.273	10374	10116	10288
PLR075	3.112	3.100	3.092	411.7	397.1	411.2	6.81	6.806	6.768	18823	18090	18787
PLR078	1.884	1.874	1.699	381.1	374.3	374.1	5.98	5.966	5.469	12000	11756	11619
PLR081	2.645	2.628	2.256	341.1	338.2	331.3	6.33	6.299	5.510	14260	14110	13563
PLR082	3.321	3.304	3.063	336.6	331.0	331.8	7.91	7.892	7.372	14133	13856	13783

PLR084	2.432	2.420	2.176	433.7	426.4	425.0	5.83	5.811	5.288	18092	17755	17493
PLR087	2.303	2.296	2.256	464.1	451.1	462.4	6.28	6.272	6.165	17029	16517	16926
PLR088	2.516	2.498	2.416	312.8	304.1	310.6	7.5	7.490	7.243	10496	10144	10362
PLR090	2.087	2.072	2.075	359.8	342.1	359.4	5.63	5.632	5.605	13332	12586	13309
PLR091	2.152	2.127	1.448	486.2	484.3	448.9	5.6	5.545	3.958	18682	18581	16421
PLR092	2.252	2.233	1.781	464.4	456.1	444.2	5.84	5.803	4.756	17909	17551	16638
PLR093	1.217	1.206	1.041	497.5	467.2	483.4	3.77	3.751	3.286	16067	15017	15314
PLR094	1.427	1.416	1.169	475.4	463.5	457.9	4.11	4.085	3.449	16521	16069	15523
PLR095	0.908	0.897	0.562	470.5	475.7	425.8	3.11	3.079	2.043	13722	13865	11704
PLR096	2.049	2.028	1.704	327.7	318.6	316.8	5.34	5.315	4.556	12574	12155	11847
PLR097	1.272	1.259	0.889	455.8	455.5	424.6	4.03	3.997	2.950	14371	14344	12796
PLR098	1.340	1.329	1.007	442.2	441.3	418.5	4.07	4.036	3.169	14574	14528	13299
PLR099	4.247	4.204	2.411	298.5	303.8	265.5	9.42	9.298	5.811	13462	13734	11017
PLR100	4.311	4.246	4.163	277.8	264.7	276.1	10.15	10.138	9.848	11803	11084	11673
PLR101	4.699	4.620	4.098	243.3	236.1	237.5	10.51	10.477	9.371	10872	10414	10385
PLR102	2.993	2.951	1.641	405.5	410.2	356.5	7.02	6.924	4.158	17289	17480	14065
PLR103	1.006	0.993	0.575	636.5	658.8	564.0	3.65	3.603	2.223	17538	18147	14594
PLR104	2.493	2.464	1.612	398.8	400.4	365.3	6.95	6.877	4.763	14304	14350	12361
PLR105	2.483	2.448	1.315	466.4	477.1	406.3	6.61	6.517	3.800	17519	17919	14062
PLR106	4.128	4.057	3.305	413.9	375.2	396.8	9.42	9.367	7.750	18130	16252	16920
PLR107	1.541	1.518	0.897	372	369.9	332.4	5.27	5.203	3.303	10880	10795	9033
PLR108	1.707	1.677	1.171	469.7	429.2	435.6	5.71	5.660	4.106	14029	12713	12417
PLR109	2.804	2.773	2.035	301.7	298.7	283.9	7.74	7.677	5.895	10931	10789	9801
PLR110	2.758	2.729	1.616	332.3	338.3	297.6	6.66	6.577	4.208	13766	14035	11428
PLR111	1.605	1.594	0.833	332.1	351.8	288.9	5.17	5.093	2.957	10319	11010	8135

Appendix D: Dispersion values

Table D-1- Dispersion values in 1995, 2005, 2015, and under Scenarios 1 to 5 across Germany's federal states and the country

DIS **(UPU/m²)**												
	Past Trend			**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5 (A & B)**	
Federal States	**1995**	**2005**	**2015**	**2021**	**2050**	**2021**	**2050**	**2021**	**2050**	**2021**	**2050**	**2021**	**2050**
Baden-Württemberg	42.935	43.326	43.721	43.806	44.062	43.766	43.807	43.763	43.801	43.738	43.753	43.721	43.721
Bayern	43.673	43.986	44.325	44.419	44.667	44.377	44.397	44.372	44.391	44.335	44.339	44.325	44.325
Berlin	48.937	48.943	48.955	NA	NA	49.062	49.192	49.041	49.553	49.044	49.155	48.95	48.955
Brandenburg	42.102	42.432	42.63	42.729	42.904	42.656	42.463	42.653	42.48	42.632	42.62	42.623	42.418
Bremen	48.018	48.108	48.161	48.23	48.47	48.196	48.222	48.236	48.293	48.182	48.198	48.16	48.161
Hamburg	48.648	48.698	48.739	43.642	43.894	48.812	48.931	48.9	49.167	48.796	48.89	48.74	48.739
Hessen	42.959	43.264	43.557	NA	NA	43.602	43.632	43.599	43.627	43.573	43.585	43.557	43.557
Mecklenburg-Vorpommern	41.125	41.545	41.769	41.87	42.092	41.767	41.507	41.768	41.535	41.769	41.753	41.759	41.432

Niedersachsen	44.192	44.551	44.885	44.983	45.271	44.916	44.864	44.913	44.866	44.89	44.882	44.884	44.859
Nordrhein-Westfalen	46.003	46.173	46.391	46.463	46.677	46.418	46.392	46.417	46.392	46.403	46.395	46.391	46.391
Rheinland-Pfalz	43.242	43.571	43.854	43.926	44.149	43.876	43.84	43.875	43.841	43.858	43.852	43.853	43.836
Saarland	45.527	45.685	45.862	45.909	46.063	45.847	45.687	45.848	45.699	45.859	45.827	45.855	45.639
Sachsen	44.887	45.136	45.29	45.382	45.538	45.296	45.033	45.296	45.054	45.291	45.253	45.28	44.96
Sachsen-Anhalt	41.608	41.916	42.15	42.211	42.273	42.12	41.747	42.123	41.789	42.148	42.128	42.136	41.622
Schleswig-Holstein	44.272	44.562	44.909	45.017	45.319	44.949	44.907	44.946	44.907	44.916	44.909	44.909	44.905
Thüringen	41.762	42.149	42.434	42.483	42.568	42.389	42.023	42.393	42.063	42.429	42.397	42.419	41.894
Germany	44.219	44.461	44.702	Warning: 44.774		No deterioration: 44.715		Limit: 44.650				Target: 44.586	

Table D- 2- Dispersion values in 1995, 2005, 2015, and under Scenarios 1 to 5 across Germany's planning regions

DIS **(UPU/m²)**												
	Past Trend			**Scenario 1**		**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5 (A & B)**	
PLR	**1995**	**2005**	**2015**	**2021**	**2050**	**2021**	**2050**	**2021**	**2050**	**2021**	**2050**	**2021**	**2050**
PLR001	43.529	43.957	44.452	44.58	44.92	44.493	44.406	44.528	44.366	44.460	44.452	44.45	44.394
PLR002	44.907	45.085	45.342	45.44	45.75	45.375	45.328	45.408	45.315	45.353	45.342	45.341	45.324
PLR003	44.380	44.643	44.933	45.04	45.33	44.977	44.949	45.016	44.964	44.941	44.936	44.93	44.93
PLR004	48.648	48.698	48.739	NA	NA	48.812	48.931	48.9	49.167	48.796	48.893	48.74	48.74
PLR005	48.018	48.108	48.161	48.23	48.47	48.196	48.222	48.236	48.293	48.182	48.198	48.16	48.16
PLR006	45.046	45.389	45.709	45.82	46.18	45.746	45.730	45.779	45.75	45.715	45.713	45.71	45.71
PLR007	43.042	43.582	43.879	43.98	44.28	43.905	43.852	43.927	43.829	43.883	43.878	43.878	43.845
PLR008	45.368	45.736	46.091	46.23	46.58	46.150	46.118	46.204	46.143	46.098	46.095	46.09	46.09
PLR009	44.292	44.920	45.393	45.51	45.9	45.410	45.326	45.424	45.267	45.393	45.387	45.391	45.309
PLR010	43.078	43.352	43.646	43.73	44.01	43.657	43.560	43.666	43.489	43.649	43.640	43.643	43.538
PLR011	44.596	45.166	45.723	45.9	46.26	45.826	45.820	45.918	45.907	45.731	45.731	45.72	45.72
PLR012	42.182	42.795	43.287	43.39	43.72	43.302	43.191	43.315	43.112	43.285	43.274	43.283	43.166
PLR013	44.874	45.224	45.565	45.67	45.92	45.602	45.518	45.635	45.476	45.565	45.558	45.563	45.506
PLR014	43.971	44.477	44.977	45.11	45.47	45.042	45.046	45.098	45.105	44.982	44.982	44.98	44.98
PLR015	43.560	44.123	44.713	44.81	45.06	44.730	44.567	44.746	44.443	44.717	44.704	44.707	44.528
PLR016	46.239	46.302	46.362	46.49	46.69	46.425	46.282	46.329	46.047	46.369	46.340	46.412	46.246
PLR017	43.018	43.341	43.585	43.66	43.95	43.588	43.496	43.591	43.42	43.584	43.571	43.581	43.473
PLR018	43.856	44.211	44.580	44.71	45.02	44.655	44.666	44.722	44.742	44.593	44.595	44.58	44.58
PLR019	43.227	43.523	43.828	43.91	44.14	43.839	43.726	43.849	43.636	43.833	43.815	43.824	43.699
PLR020	41.084	41.368	41.575	41.66	41.93	41.567	41.380	41.56	41.218	41.576	41.559	41.567	41.326
PLR021	45.208	45.657	46.035	46.15	46.54	46.067	46.038	46.096	46.04	46.041	46.038	46.04	46.04
PLR022	40.951	41.354	41.652	41.71	41.97	41.626	41.473	41.605	41.33	41.650	41.645	41.645	41.424
PLR023	42.844	43.219	43.494	43.58	43.78	43.545	43.555	43.588	43.607	43.501	43.502	43.49	43.49
PLR024	42.837	43.181	43.555	43.66	43.91	43.583	43.444	43.606	43.352	43.555	43.547	43.551	43.414
PLR025	41.301	41.643	41.907	41.98	42.21	41.888	41.677	41.873	41.487	41.906	41.888	41.898	41.613
PLR026	44.493	44.940	45.408	45.53	45.85	45.459	45.410	45.505	45.412	45.415	45.410	45.41	45.41
PLR027	44.285	44.795	45.429	45.53	45.83	45.458	45.399	45.485	45.371	45.434	45.427	45.428	45.391

PLR028	45.209	45.476	45.788	45.9	46.24	45.820	45.761	45.85	45.737	45.791	45.781	45.787	45.755
PLR030	41.070	41.657	42.110	42.21	42.47	42.140	42.067	42.164	42.031	42.114	42.107	42.109	42.056
PLR031	45.370	45.660	45.892	45.99	46.28	45.911	45.808	45.927	45.732	45.898	45.888	45.889	45.786
PLR032	43.130	43.520	43.862	43.96	44.21	43.900	43.851	43.932	43.842	43.863	43.856	43.862	43.848
PLR033	41.700	41.983	42.244	42.32	42.58	42.244	42.137	42.243	42.05	42.240	42.233	42.24	42.109
PLR034	45.227	45.728	46.173	46.3	46.55	46.253	46.273	46.327	46.366	46.186	46.189	46.17	46.17
PLR035	44.211	44.513	44.846	44.95	45.21	44.894	44.856	44.935	44.864	44.850	44.845	44.85	44.85
PLR036	43.871	44.106	44.495	44.6	44.94	44.502	44.384	44.507	44.289	44.497	44.487	44.491	44.355
PLR037	42.742	43.370	44.320	44.44	44.83	44.329	44.206	44.336	44.11	44.323	44.317	44.316	44.175
PLR038	45.458	45.657	45.806	45.88	46.11	45.843	45.850	45.881	45.896	45.820	45.823	45.81	45.81
PLR039	43.415	43.726	43.988	44.06	44.29	44.006	43.929	44.022	43.876	43.995	43.980	43.986	43.914
PLR040	47.761	47.932	48.053	48.1	48.38	48.061	48.113	48.07	48.176	48.058	48.075	48.05	48.05
PLR041	46.970	47.180	47.213	47.22	47.37	47.177	47.115	47.141	47.015	47.204	47.188	47.209	47.089
PLR043	48.473	48.542	48.647	48.73	48.84	48.712	48.750	48.786	48.868	48.683	48.703	48.65	48.65
PLR044	48.487	48.522	48.596	48.66	48.81	48.641	48.670	48.694	48.757	48.623	48.641	48.6	48.6
PLR045	46.841	47.082	47.190	47.28	47.57	47.200	47.098	47.211	47.006	47.191	47.164	47.186	47.074
PLR046	45.693	45.861	46.094	46.17	46.4	46.114	46.055	46.132	46.017	46.102	46.089	46.093	46.045
PLR047	46.248	46.386	46.592	46.67	46.88	46.635	46.653	46.682	46.718	46.615	46.624	46.59	46.59
PLR048	47.842	47.892	47.973	48.03	48.22	47.992	47.960	48.013	47.945	47.984	47.966	47.973	47.957
PLR049	44.108	44.341	44.545	44.61	44.83	44.536	44.400	44.527	44.261	44.545	44.505	44.539	44.361
PLR050	46.920	47.061	47.236	47.31	47.5	47.271	47.259	47.312	47.286	47.257	47.250	47.24	47.24
PLR051	45.205	45.496	45.905	45.98	46.18	45.941	45.915	45.976	45.926	45.913	45.907	45.9	45.9
PLR052	41.993	42.380	42.737	42.83	43.12	42.751	42.664	42.763	42.603	42.736	42.724	42.734	42.646
PLR053	41.882	42.241	42.564	42.64	42.89	42.583	42.540	42.599	42.518	42.572	42.563	42.564	42.534
PLR054	45.004	45.171	45.369	45.45	45.63	45.432	45.516	45.501	45.679	45.406	45.456	45.37	45.37
PLR055	43.761	44.100	44.367	44.46	44.73	44.388	44.310	44.407	44.259	44.368	44.354	44.365	44.295
PLR056	43.026	43.389	43.685	43.75	43.91	43.718	43.715	43.749	43.744	43.695	43.695	43.68	43.68
PLR057	44.785	45.011	45.234	45.3	45.48	45.272	45.311	45.31	45.388	45.248	45.263	45.23	45.23
PLR058	41.773	42.167	42.544	42.63	42.97	42.549	42.497	42.553	42.457	42.547	42.540	42.542	42.485
PLR059	42.866	43.188	43.441	43.51	43.75	43.435	43.325	43.43	43.225	43.444	43.430	43.436	43.294
PLR060	45.527	45.685	45.862	45.91	46.07	45.847	45.686	45.833	45.518	45.858	45.826	45.855	45.637
PLR061	43.345	43.666	44.134	44.22	44.49	44.178	44.199	44.217	44.257	44.139	44.143	44.13	44.13
PLR062	42.401	42.919	43.448	43.56	43.87	43.508	43.552	43.558	43.64	43.458	43.464	43.45	43.45
PLR063	42.509	42.985	43.391	43.49	43.75	43.447	43.471	43.496	43.541	43.400	43.405	43.39	43.39
PLR064	43.399	43.709	44.047	44.12	44.37	44.081	44.126	44.113	44.2	44.061	44.074	44.05	44.05
PLR065	44.103	44.344	44.656	44.7	44.76	44.693	44.702	44.73	44.749	44.674	44.678	44.66	44.66
PLR066	42.408	42.798	43.184	43.27	43.53	43.228	43.266	43.269	43.341	43.194	43.205	43.18	43.18
PLR067	41.946	42.375	42.772	42.88	43.23	42.815	42.849	42.854	42.921	42.786	42.798	42.77	42.77
PLR068	42.260	42.796	43.175	43.27	43.62	43.200	43.184	43.222	43.191	43.178	43.175	43.18	43.18
PLR069	40.976	41.509	42.025	42.12	42.44	42.061	42.065	42.092	42.101	42.030	42.031	42.02	42.02
PLR070	45.352	45.621	45.888	45.96	46.16	45.940	46.003	45.997	46.13	45.918	45.956	45.89	45.89
PLR071	43.585	43.867	44.208	44.29	44.5	44.265	44.321	44.321	44.431	44.226	44.247	44.21	44.21
PLR072	43.480	43.837	44.253	44.36	44.65	44.303	44.313	44.35	44.368	44.266	44.268	44.25	44.25
PLR073	43.463	43.773	44.146	44.25	44.52	44.207	44.261	44.261	44.363	44.153	44.162	44.15	44.15

PLR074	43.773	44.088	44.376	44.44	44.65	44.398	44.354	44.418	44.335	44.377	44.367	44.375	44.349
PLR075	44.593	44.824	45.138	45.25	45.54	45.183	45.133	45.222	45.128	45.145	45.141	45.138	45.131
PLR076	43.648	43.962	44.245	44.33	44.48	44.315	44.366	44.376	44.472	44.253	44.260	44.24	44.24
PLR077	44.994	45.211	45.625	45.72	45.96	45.679	45.690	45.726	45.747	45.632	45.633	45.62	45.62
PLR078	40.460	41.028	41.430	41.52	41.75	41.449	41.342	41.465	41.269	41.430	41.420	41.427	41.319
PLR079	45.938	46.032	46.224	NA	NA	46.304	46.414	46.394	46.626	46.270	46.336	46.22	46.22
PLR080	45.951	46.087	46.198	46.28	46.49	46.255	46.312	46.314	46.43	46.219	46.243	46.2	46.2
PLR081	43.730	44.102	44.409	44.52	44.85	44.415	44.274	44.42	44.157	44.409	44.394	44.404	44.238
PLR082	43.862	44.142	44.478	44.56	44.81	44.496	44.409	44.512	44.348	44.479	44.468	44.475	44.391
PLR083	42.782	43.058	43.415	43.52	43.8	43.464	43.476	43.507	43.531	43.426	43.429	43.42	43.42
PLR084	43.520	43.808	44.093	44.18	44.42	44.110	43.997	44.124	43.917	44.092	44.084	44.089	43.972
PLR085	44.044	44.285	44.549	44.65	44.86	44.610	44.628	44.663	44.697	44.556	44.558	44.55	44.55
PLR086	45.196	45.461	45.863	45.97	46.27	45.916	45.946	45.965	46.024	45.871	45.876	45.86	45.86
PLR087	41.564	42.207	42.745	42.85	43.13	42.779	42.727	42.807	42.713	42.750	42.747	42.744	42.723
PLR088	41.435	41.855	42.342	42.42	42.6	42.376	42.308	42.404	42.279	42.349	42.339	42.341	42.299
PLR089	48.937	48.943	48.955	NA	NA	49.062	49.192	49.041	49.553	49.046	49.157	48.95	48.95
PLR090	42.477	42.877	43.094	43.2	43.37	43.156	43.089	43.208	43.085	43.102	43.096	43.094	43.088
PLR091	42.633	42.920	43.169	43.26	43.4	43.162	42.837	43.156	42.569	43.169	43.155	43.157	42.739
PLR092	42.861	43.069	43.238	43.33	43.53	43.252	43.038	43.264	42.876	43.240	43.229	43.23	42.983
PLR093	40.885	41.269	41.453	41.6	41.76	41.526	41.319	41.584	41.212	41.455	41.444	41.448	41.283
PLR094	41.651	42.027	42.197	42.3	42.51	42.222	42.027	42.242	41.89	42.200	42.190	42.19	41.98
PLR095	39.858	40.307	40.481	40.57	40.73	40.453	40.081	40.43	39.751	40.483	40.467	40.467	39.957
PLR096	43.104	43.439	43.587	43.71	43.99	43.616	43.431	43.641	43.299	43.589	43.567	43.581	43.389
PLR097	40.509	40.989	41.277	41.38	41.6	41.266	40.977	41.258	40.733	41.278	41.264	41.266	40.889
PLR098	41.030	41.446	41.733	41.82	42.06	41.727	41.492	41.721	41.297	41.729	41.716	41.724	41.424
PLR099	45.054	45.359	45.535	45.61	45.72	45.498	45.081	45.463	44.671	45.531	45.483	45.519	44.936
PLR100	44.536	44.817	45.053	45.17	45.39	45.112	45.024	45.166	44.996	45.069	45.051	45.052	45.016
PLR101	46.027	46.153	46.184	46.27	46.41	46.216	46.071	46.248	45.96	46.195	46.158	46.179	46.041
PLR102	43.930	44.217	44.389	44.47	44.51	44.358	43.899	44.331	43.489	44.390	44.365	44.372	43.739
PLR103	39.040	39.379	39.737	39.78	39.84	39.678	39.271	39.629	38.883	39.735	39.726	39.721	39.121
PLR104	42.038	42.430	42.652	42.72	42.78	42.634	42.292	42.619	41.998	42.653	42.631	42.639	42.183
PLR105	42.652	42.813	42.973	43.03	43.03	42.927	42.456	42.889	42.039	42.970	42.951	42.955	42.285
PLR106	44.302	44.484	44.658	44.86	44.99	44.772	44.467	44.87	44.306	44.672	44.649	44.65	44.415
PLR107	40.006	40.475	40.731	40.82	40.85	40.722	40.291	40.715	39.923	40.734	40.705	40.716	40.151
PLR108	39.954	40.395	40.720	40.91	40.91	40.821	40.404	40.902	40.145	40.730	40.708	40.709	40.311
PLR109	42.468	42.859	43.171	43.25	43.38	43.174	42.909	43.176	42.684	43.172	43.137	43.161	42.834
PLR110	43.781	44.110	44.357	44.42	44.52	44.319	43.924	44.286	43.552	44.349	44.314	44.341	43.787
PLR111	40.844	41.232	41.488	41.51	41.58	41.399	40.968	41.323	40.532	41.480	41.445	41.47	40.796

Table D- 3- Proposed targets, limits, no-deterioration, and warning values for Germany's federal states (DIS values)

DIS **(UPU/m²)**									
States with decreasing population	**Warning**	**No deterioration**	**Limit**	**Target**	**States with increasing population**	**Warning**	**No deterioration**	**Limit**	**Target**
Brandenburg	42.6768	42.62	42.519	42.418	Baden-Württemberg	43.777	43.753	43.737	43.721
Mecklenburg-Vorpommern	41.8208	41.753	41.5925	41.432	Bayern	44.365	44.339	44.332	44.325
Niedersachsen	44.9598	44.882	44.8705	44.859	Berlin	49.354	49.155	49.0525	48.95
Rheinland-Pfalz	43.9114	43.852	43.844	43.836	Bremen	48.2455	48.198	48.179	48.16
Saarland	45.8742	45.827	45.733	45.639	Hamburg	49.0285	48.89	48.815	48.74
Sachsen	45.31	45.253	45.1065	44.96	Hessen	43.606	43.585	43.571	43.557
Sachsen-Anhalt	42.157	42.128	41.875	41.622	Nordrhein-Westfalen	46.3935	46.395	46.393	46.391
Schleswig-Holstein	44.991	44.909	44.907	44.905					
Thüringen	42.4312	42.397	42.1455	41.894					

Table D- 4- Proposed targets, limits, no-deterioration, and warning values for Germany's planning regions (DIS values)

DIS **(UPU/m²)**									
PLRs with decreasing population	**Warning**	**No deterioration**	**Limit**	**Target**	**PLRs with increasing population**	**Warning**	**No deterioration**	**Limit**	**Target**
PLR001	44.542	44.447	44.421	44.394	PLR003	44.950	44.936	44.935	44.933
PLR002	45.421	45.339	45.331	45.324	PLR004	49.031	48.895	48.817	48.739
PLR007	43.957	43.876	43.861	43.845	PLR005	48.247	48.200	48.181	48.161
PLR009	45.490	45.388	45.348	45.309	PLR006	45.731	45.712	45.710	45.709
PLR010	43.712	43.637	43.588	43.538	PLR008	46.118	46.094	46.092	46.091
PLR012	43.365	43.277	43.221	43.166	PLR011	45.820	45.732	45.728	45.723
PLR013	45.633	45.561	45.533	45.506	PLR014	45.043	44.982	44.979	44.977
PLR015	44.773	44.701	44.615	44.528	PLR018	44.669	44.596	44.588	44.580
PLR016	46.405	46.334	46.290	46.246	PLR021	46.037	46.035	46.035	46.035
PLR017	43.647	43.571	43.522	43.473	PLR023	43.556	43.505	43.500	43.494
PLR019	43.876	43.810	43.754	43.699	PLR026	45.410	45.408	45.408	45.408
PLR020	41.631	41.556	41.441	41.326	PLR034	46.277	46.189	46.181	46.173
PLR022	41.710	41.645	41.534	41.424	PLR035	44.855	44.847	44.846	44.846
PLR024	43.621	43.548	43.481	43.414	PLR038	45.861	45.826	45.816	45.806

PLR025	41.949	41.884	41.749	41.613
PLR027	45.506	45.425	45.408	45.391
PLR028	45.875	45.783	45.769	45.755
PLR030	42.179	42.106	42.081	42.056
PLR031	45.963	45.884	45.835	45.786
PLR032	43.930	43.860	43.854	43.848
PLR033	42.306	42.238	42.173	42.109
PLR036	44.576	44.485	44.420	44.355
PLR037	44.417	44.314	44.245	44.175
PLR039	44.039	43.976	43.945	43.914
PLR041	47.222	47.185	47.137	47.089
PLR045	47.246	47.165	47.119	47.074
PLR046	46.148	46.086	46.065	46.045
PLR048	48.016	47.965	47.961	47.957
PLR049	44.565	44.499	44.430	44.361
PLR052	42.804	42.725	42.686	42.646
PLR053	42.626	42.560	42.547	42.534
PLR055	44.431	44.356	44.326	44.295
PLR058	42.625	42.538	42.512	42.485
PLR059	43.489	43.424	43.359	43.294
PLR060	45.874	45.825	45.731	45.637
PLR074	44.426	44.370	44.360	44.349
PLR075	45.218	45.138	45.134	45.131
PLR078	41.487	41.422	41.370	41.319
PLR081	44.484	44.393	44.316	44.238
PLR082	44.537	44.469	44.430	44.391
PLR084	44.153	44.086	44.029	43.972
PLR087	42.821	42.744	42.734	42.723
PLR088	42.390	42.337	42.318	42.299
PLR090	43.149	43.094	43.091	43.088
PLR091	43.203	43.153	42.946	42.739
PLR092	43.286	43.226	43.104	42.983
PLR093	41.509	41.446	41.365	41.283
PLR094	42.252	42.187	42.084	41.98
PLR095	40.515	40.461	40.209	39.957
PLR096	43.651	43.566	43.478	43.389
PLR097	41.328	41.259	41.074	40.889
PLR098	41.787	41.719	41.571	41.424
PLR099	45.524	45.476	45.206	44.936
PLR100	45.116	45.047	45.032	45.016
PLR101	46.205	46.153	46.097	46.041
PLR102	44.388	44.357	44.048	43.739
PLR103	39.748	39.724	39.423	39.121
PLR104	42.657	42.627	42.405	42.183

PLR040	48.125	48.074	48.064	48.053
PLR043	48.786	48.704	48.675	48.647
PLR044	48.699	48.642	48.619	48.596
PLR047	46.671	46.623	46.608	46.592
PLR050	47.268	47.250	47.243	47.235
PLR051	45.917	45.908	45.906	45.905
PLR054	45.569	45.458	45.414	45.369
PLR056	43.719	43.694	43.690	43.685
PLR057	45.326	45.264	45.249	45.234
PLR061	44.203	44.149	44.141	44.134
PLR062	43.552	43.464	43.456	43.449
PLR063	43.475	43.408	43.400	43.391
PLR064	44.136	44.073	44.060	44.047
PLR065	44.713	44.676	44.666	44.656
PLR066	43.275	43.209	43.197	43.184
PLR067	42.861	42.801	42.787	42.772
PLR068	43.184	43.176	43.176	43.175
PLR069	42.069	42.036	42.030	42.025
PLR070	46.045	45.959	45.924	45.888
PLR071	44.342	44.252	44.230	44.208
PLR072	44.319	44.270	44.262	44.253
PLR073	44.264	44.166	44.156	44.146
PLR076	44.367	44.261	44.253	44.244
PLR077	45.689	45.630	45.628	45.625
PLR079	46.483	46.340	46.282	46.223
PLR080	46.338	46.246	46.222	46.198
PLR083	43.480	43.429	43.422	43.415
PLR085	44.628	44.559	44.554	44.549
PLR086	45.950	45.877	45.870	45.863
PLR089	49.359	49.166	49.060	48.955

PLR105	42.965	42.949	42.617	42.285
PLR106	44.712	44.643	44.529	44.415
PLR107	40.727	40.697	40.424	40.151
PLR108	40.745	40.704	40.507	40.311
PLR109	43.183	43.133	42.984	42.834
PLR110	44.353	44.312	44.049	43.787
PLR111	41.466	41.438	41.117	40.796