Just Transitions in Urban Planning: Mapping (In)Justice in Munich

Bachelor Thesis

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ABSTRACT

To respond to the multitude of challenges arising from increasing growth and density, climate change, demographic shift and socio-economic divergences, cities often employ informal planning instruments such as city development plans to establish a long-term vision. In such planning programs, Green Infrastructure Planning is often embraced as the main principle since it offers a holistic approach of integrated planning. While the performance assessment of the ecological and economical impact of GI planning are common and partially standardized procedures, little is known about the social implications of GI planning. Considering the globally observed increase in social-economical inequalities that is likely to be aggravated by the unequal exposure and adaptive capacities of different stakeholders to climate change effects, there is a need to address the socio-ecological impact of GI planning. This study analyzed the recently adopted renewal of the city development plan of Munich with respect to its socio-ecological influence utilizing a justice mapping of the city conducted by the EU-Project JUSTNature. A plan evaluation methdology was developed that makes the (mis)matches of requirement and provision of different socio-ecological justice dimensions spatially explicit. Seven neighborhoods were identified as critical due to an unmet demand of GI interventions planned within the strategic devleopment plan. The findings show that for the city of Munich, priority areas for GI intervention shift notably from the inner-city areas to the peripheral neighborhoods when considering societal challenges next to ecological challenges in the planning process.

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01 Introduction

1. Introduction

Research Problem

In recent years, cities have been at the forefront of addressing the complex challenges arising from rapid urbanization and climate change. These challenges, compounded by increasing population densities, demographic shifts, and socio-economic disparities, necessitate robust planning frameworks that can simultaneously accommodate social, economic, and environmental sustainability. Cities often adopt long-term planning frameworks such as city development plans to address these issues. In such planning, Green Infrastructure (GI) has become a central strategy, gaining widespread attention for its ability to address the multifaceted challenges cities face. (Pauleit et al., 2011, 2019) GI offers a holistic approach to urban development by enhancing ecosystem services such as air and water quality, biodiversity, and climate resilience, while at the same time improving the quality of life for urban residents. The key principle of GI planning is hence the combination of ecological, economic and social reasoning to mitigate environmental risks, as well as build resilience to extreme weather events. (Pauleit et al., 2017) The increasing occurrence of such events in recent years have not only highlighted the economic importance of urban green infrastructure, regarding i.e. its stormwater retention capacity, but also brought to attention the interconnectedness of natural systems and human activities and its close link with the well-being of human and non-human stakeholders. (Chiesura, 2004; Wolch et al., 2014) Its significance on public health was furthermore underscored by the COVID-19 pandemic, as it made the benefits of urban green spaces particularly tangible for urban dwellers (Fagerholm et al., 2022; Stuhlmacher & Kim, 2024). This, next to the growing awareness of climate change, accelerated the adoption of GI planning approaches and their implementation through nature-based solutions (NBS), thus "solutions that are inspired and supported by nature" (European Commission, 2023).

However, although the increase in livability is considered one of the key drivers in the adoption of GI planning, the social-cultural impact of these interventions often remains unexplored or vague. At the same time, the performance assessment of the ecological and economic benefits of GI a widely recognized procedure and partially institutionalized through frameworks such as Nature Capital Accounting (NCA) or Ecosystem Service Evaluation which allow for a precise quantification of economic and ecological gains or losses by GI interventions (Costanza et al., 1997; European Commission. Joint Research Centre., 2020). This knowledge gap is particularly concerning given the increasing socio-economic inequalities observed globally, which are likely to be exacerbated by climate change. (Stuhlmacher & Kim, 2024; UNDP, 2023) This affects both the benefits provided by GI, such as access to green spaces, as well as the risks of insufficient urban green infrastructure, which eventually translates to differences in climate change vulnerability due to higher risk exposure and lower adaptive capacities (Harlan et al., 2015; Wolch et al., 2014). In densely populated cities like Munich, where approximately 47% of the land is sealed and the income inequality is nationwide above the average, these differences in access and exposure to environmental benefits and burdens are not trivial (Demografieportal, 2022). Without an evaluation of the third pillar of the GI planning principles - the social benefits - it remains unknown whether GI interventions can deliver what they promise, or if even unfavorable social impacts might be created.

A growing recognition of the socio-economic dimensions of GI in recent years has led to increasing calls for its integration into urban planning not just as an environmental tool but also as a means of addressing urban (in)justice. Several initiatives have emerged to better understand and measure the social implications of GI. The concept of spatial, environmental or socio-ecological justice in urban planning, which emphasizes fairness in the distribution of both ecological and social goods, has thereby gained traction as a critical lens for understanding and addressing urban inequalities (Chatterton, 2010; Monteiro et al., 2020; Schlosberg, 2007) Such approaches usually involve a tripartite framework that includes distributional, recognitional, and procedural equity. This framework helps planners identify who benefits from urban developments and who may be left out, thus fostering a more inclusive approach to decision-making. (Gantioler et al., 2023; Langemeyer et al., 2016; Moroni, 2020) Notions of justice have also found their way into international agendas, such as the "leave no one behind"-principle within the European Green Deal, which recognizes that "the most vulnerable are the most exposed to the harmful effects of climate change and environmental degradation" (European Commission, 2019, point 2.2.1). The European Environment Agency (EEA) has refined the approach of a Just Transition within a new Policy Framework, laying out the core principles of justice in the context of sustainability transitions by following the previously outlined three core dimensions of justice (EEA, n.d.). These frameworks - such as the here employed justice mapping undertaken for the case study of Munich by the EU-Project JUSTNature - deliver the groundwork for a socio-ecological just planning, as they firstly assess the status quo in terms of socio-ecological equity, which can then be used to inform future planning (Gantioler et al., 2023; Loos et al., 2023). The just recently adopted renewal of Munich's city development plan offers the opportunity to evaluate the plan's socio-ecological impact in a quantitative manner using the JUSTNature justice assessment for the city of Munich. Although social inclusion and equity are

not explicitly expressed as one of the goals in the plan, this aspect is emphasized in the intention statement of the plan as well as throughout the explanatory documentation.

Research Aim

Reviewing how GI planning matches with its socio-cultural objectives and thus evaluating whether the promises of a fair transition are likely to be met for the case study of Munich, the thesis aims to contribute to the mainstreaming of systematic socio-ecological justice assessments for GI planning. This thesis argues that in order to include socio-ecological objectives in urban planning reliably and thoroughly, a systematic assessment of the status quo and planning strategy concerning their socio-ecological impact is required. Only by establishing a systematic procedure for the evaluation, urban (in)justice concerns can be comprehensively understood, and therefore interventions implemented that address them sufficiently, avoiding an unintentional perpetuation of existing patterns of injustice.

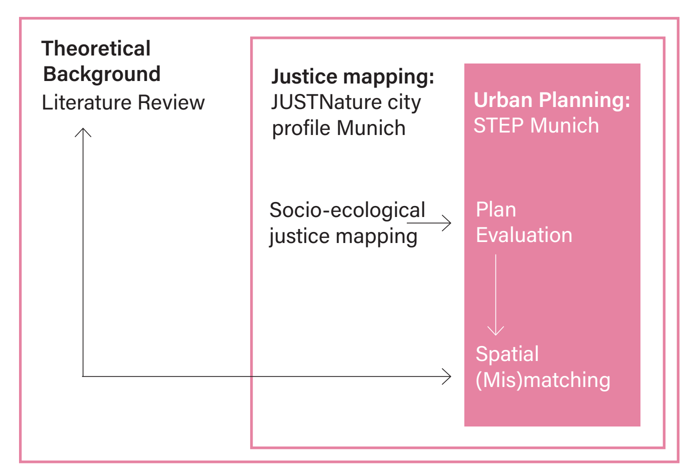

FIGURE 1: SCOPE AND METHOD OF RESEARCH

Research Questions and Methods

Within this Thesis, a Literature Review was conducted to gain an understanding of justice frameworks and indicator selection in urban planning. Aiming to contribute to the development of systematic socio-ecological justice assessments in urban planning, a methodology was developed on the case study for the city of Munich utilizing a justice mapping undertaken by the JUSTNature-Project for the city of Munich, as well as the city's current development plan (STEP2040). By spatially overlaying the demand and provision of different socio-demographic and environmental indicators, the (mis)alignment of green infrastructure interventions were evaluated in order to identify neighborhoods that are at risk of being a blind spot for socio-ecological justice. Insights from this analysis were then contextualized by other socio-ecological justice assessments of Munich to draw conclusions on the validity and potential of the findings based on the JUSTNature approach.
The Thesis hence aims to answer the following questions via a mixed-methods approach:

Conceptual Question:
- How can urban planning more effectively integrate socio-ecological justice considerations in the context of climate adaptation and limited resources?

Theoretical Background:
- Which frameworks and indicators of justice are currently used in urban planning?
- How do social and ecological variables interplay across different cities?

Case Study Munich:
- How can mismatches in the demand and provision of green infrastructure be methodologically detected and evaluated in urban planning contexts?
- What are the strengths and limitations of quantifying strategic plans using digital methods?
- How does indicator selection influence the identification of vulnerable areas?

02 Theoretical Background

2. Theoretical Background: Justice in the context of urban planning

Search Criteria for Literature

To understand which assessment methods of socio-ecological justice are currently employed in urban planning, nine case studies of urban justice assessments were reviewed. The publications were identified via a Web of Science Search Regime that yielded 2,229 results. A further refinement narrowed down the amount to 67, out of which nine publications were specifically focusing on assessments or frameworks for socio-ecological justice in the urban context. The search regime was hence 1) socio-ecological justice assessment *OR* framework 2) in spatial planning *OR* urban planning *OR) cities. General literature about environmental justice approaches, ecosystem service evaluation or green infrastructure was thus excluded. Table 01 gives an overview of the considered justice frameworks, their scope and elaboration of each justice dimension.

Indicator selection

It becomes evident that throughout almost all case studies, there was a strong focus on the distributional justice dimension. This is congruent with the findings from background literature, as there is a historically strong focus on the distributional dimension in urban planning. Moreover, this could be explained by the relatively straightforward assessment methods for the socio-ecological justice distribution due to its spatial character, compared to the less spatially explicit nature of the recognitional and procedural dimension. Studies that focused equally on all three dimensions were either general frameworks without application such as in Langemeyer & Connolly (2020) and Okamoto & Doyon (2024) or case studies conducted by Pineda Pinto et al. (2021).

All frameworks follow the idea of uncovering spatial mismatches in the provision of ecosystem services by comparing the demand for certain ecosystem services with the provided services, which will then allow for the identification of areas where the demand is (un)met. Langemeyer & Connolly (2020) further investigate this by proposing not only a local assessment of spatial mismatches but also a regional, national, and global analysis. While this is unpractical for the planning strategy of a region/ city, their approach of expanding the time dimension offers a more promising perspective that has been partially considered in the JustNature approach with the inclusion of the soil sealing change between 2018 and 2020. Supposing that existing (in) equalities in cities are prone to be reproduced if their patterns are not understood, Langemeyer & Connolly, 2020 propose an analysis of the historical past in addition to the recent past, as well as of the short-term and long-term future. Okamoto & Doyon (2024) emphasize this aspect by including an intergenerational dimension in their justice framework. Next to the aspect of time, all three frameworks emphasize the aspect of recognition and participation. While Langemeyer & Connolly (2020) and Okamoto & Doyon (2024) take on a human-centered perspective in which it ultimately remains unclear how the level of inclusion of different values and perceptions in city planning can be assessed, Pineda-Pinto et al. (2021) presents a more hands-on approach. Aiming to better represent non-human stakeholders, preferences and participation are expressed by the political landscape or engagement in a district (i.e. green voters) but were not linked to conventional socio-demographic data. This differs from the JUSTNature approach, as different needs of non-human stakeholders are not represented by the indicators. Although the aspect of capability, hence individual differences in coping with environmental burdens due to socio-demographic characteristics, is reflected in all of the investigated frameworks, none of them transfers the capability approach to non-human stakeholders, as i.e. differentials of species' vulnerability to increasing temperatures.

Intersection of Justice and GI planning

All studies analyzed found disproportionality in the provision of green infrastructure, as marginalized or disadvantaged groups received fewer benefits from urban green infrastructure and ecosystem services. Lee et al. (2019) i.e. identified socio-ecological injustices in public housing estates in Hong Kong, where aging populations and language minorities had the least access to urban trees, reflected in both low tree density and diversity (Lee et al., 2019). Similarly, in a study by Escobedo et al. (2015) the poorest neighborhoods of Bogota were found to have the smallest trees, lowest canopy cover, and least tree diversity, while affluent areas in the north possess the largest trees and greatest diversity (Escobedo et al., 2015). Zhou et al. (2023) concluded that socio-economically deprived communities, especially in West and North Belfast, are most exposed to urban heat due to underinvestment in green infrastructure (Zhou et al., 2023). Suárez et al. (2020) identified that areas with a higher percentage of migrants and low-income households had less access to daily recreational areas in Oslo. Conversely, higher-income households enjoyed greater accessibility to these spaces. (Suárez et al., 2020). However, when investigating these findings more closely, it becomes evident that the demographic patterns change throughout the cities, which complicates the transferability of the results as the most disadvantaged groups differed by city. In Hong Kong, language minorities and the elderly are most deprived; in Bogotá, low-income residents in the south and west; in Belfast, deprivation is spatially concentrated in inner-city and western/northern districts, but elderly and female populations are actually better served. It can hence be concluded that the socio-economic status as measured in income is the only consistent predictor of green infrastructure distribution. Furthermore, as elderlies and children are widely known to have less physical capabilities for climate change adaptation independently of the national context, the indicators "aging index" and "families with children" are also considered in this analysis (Heaviside et al., 2017; Rouf & Wainwright, 2020).

THEORETICAL BACKGROUND

Reference (by year)	Problem Definition Scope	Scale/ Place	Indicators ecological	socio-demographic	Findings
Escobedo et al., 2015	Spatial equity in key tree structural characteristics and ESS predictors from public urban forests in Bogotá	Case Study Bogotá	Tree Size and Crown Attributes Tree Diversity Carbon Stocks Particulate Matter Removal Potential	Socioeconomic Strata	Included Land Use Types and Property Values Findings: **Tree Size and Diversity:** Affluent northern areas exhibited larger trees and greater species diversity, while poorer strata had smaller trees and less diversity. **Carbon Stocks:** Higher carbon sequestration was observed in residential areas, particularly those in wealthier neighborhoods. **Particulate Matter Removal:** The capacity for pollution mitigation was directly proportional to socioeconomic status, favoring wealthier areas.
Lee et al., 2019	Tree density and diversity in Hong Kong's public housing estates: From provision injustice to socio-ecological inclusiveness	Hong Kong	Population size Gender imbalance Median age Dependent population Single-family population Ethnic minority Language minority Pre-tertiary education attainment Commuter population Non-working population Non-tertiary worker population Domestic household Rent-to-income ratio	Tree Strems Species richness Simpson Reciprocal Index Shannon-Wiener Diversity Index Pielou Evenness index Basal area density Crown area density Tree density	Socio-ecological injustice is evident in public housing estates, where aging populations and language minorities have the least access to urban trees, reflected in both low tree density and diversity.
Langemeyer & Connolly, 2020	Analytical foundation for justice in urban ecosystem service assessments by presenting a model that integrates the co-production of urban ecosystem services with recognition, procedural, and distributional justice	General Framework	Availability and Accessibility of Infrastructure: Ecosystems, Build Structure Preferences & Needs that shape Perceptions: Benefits & Burdens Framing and Participation fostered by Institutions: Governance, Agency		**Emphasize on Space & Time:** Spatial: Downscale, Interscale Temporal Past: Historic Past, Recent Past Temporal Future: Short term future, long term future
Suarez et al., 2020	Mapping of nature-based outdoor recreation opportunities in the Oslo metropolitan area	Case Study Oslo	Degree of naturalness Tree Density Proximity to lakes and fjord Size of continuous forests Walking accessibility	household income nationality age preferences for outdoor recreation	Adopt **supply and demand approach** to identify (un)met requirements **Recreational Preferences:** The majority of participants favored large wooded areas with dense tree coverage and proximity to water. Preferences varied by age; older individuals preferred natural areas near water, while younger people favored urban spaces with recreational facilities. **Social Disparities:** Census tracts with higher percentages of migrants and low-income households have less access to daily recreational areas. Conversely, higher-income households enjoy greater accessibility to these spaces
Pineda-Pinto et al., 2021	Identification of ecological (in)justice hotspots through the social-ecological-technological system (SETS) framework	Case Study New York	Distribution of activities that harm the environment: Number of points releasing pollutants per km2 Areas that have been identified as polluted and are required to be restored: Number of remediation sites per km2 Areas that have been identified as needed to be protected by a policy: % Area that is not protected Magnitude of actual effort carried out in environmental stewardship: Time reported on stewardship activities on trees	Presence of stewardship groups that may advocate for environmental stewardship: Number of stewardship groups	Inclusion of **non-human** Interests: How is human and nonhuman nature represented? What is the level of concern for ecosystem health, nonhuman and human wellbeing? Who represents nature? Are their processes and platforms to engage with nature, build ecological knowledge, capacity transfer, and better manage ecosystems?
Pineda-Pinto et al., 2021	Mapping of social-ecological injustices in Melbourne aiming to operationalize justice assessments using a framework as systematic methodology	Case Study Melbourne	Polluting facilities Contaminated sites Extractive industries Future urbanised land Future industrial land Native vegetation	Environmental groups Green voters	Acknowledgement of multiple social-ecological actors and networks (as multispecies that co-inhabit within and across ecosystems). Emphasizes differences in **Capabilities** of Individuals
Ohlmeyer et al., 2022	Integration of provision and accessibility of urban green infrastructure in Bottrop into strategic planning instrument of city	Case Study Bottrop	Supply of public green and open spaces [GSup] Accessibility of public green and open spaces [GAcc] Noise pollution (NOI) PM10/PM2.5 pollution (PM) NOx pollu- tion (NOx) Hot days (HD) Tropical nights (TN) Flood risk (Fld)	SGB II and SGB XII recipients	**Green Space Distribution:** Certain districts, particularly in the densely urbanized southern part of the city, exhibited a shortage of public green spaces per inhabitant, falling below the recommended 6 m²/person standard. **Exposure to Environmental Burdens:** Districts with higher percentages of welfare recipients often faced greater exposure to noise and air pollution, as well as increased vulnerability to heatwaves and flooding events.
Zhou et al., 2023	Exploration of how green infrastructure influences the urban heat island effects experienced by communities across the socio-economic strata found	Case Study Belfast	Multiple and Scale-Composite Greenness Metrics	Socio-Economic Status Population Demographics	**Heat Exposure Disparities:** Socio-economically deprived communities experience higher urban heat levels, indicating unequal GI distribution. **Spatial Patterns of Greenness:** Suburban areas exhibit more extensive GI compared to inner-city regions, with South and East Belfast having better GI coverage than West and North Belfast. **Demographic Correlations:** Communities with higher percentages of female and elderly residents tend to have more GI and reduced heat exposure, suggesting that environmental injustices in GI provision and heat adaptation are influenced by underlying socio-economic dynamics
Okamoto & Doyon, 2024	Equity and justice evaluation in urban coastal adaptation planning to promote transformative, just solutions in response to sea level rise and coastal flood risks	General Framework	/		**Intergenerational** (Think across generations) & **Epistemic** (Honor different ways of knowing and being) as fourth & fifth Justice dimension Misrecognition Accountability: repair Historic, present, and future harm

TABLE 01: LITERATURE REVIEW OF JUSTICE FRAMEWORKS IN URBAN PLANNING

03 Data and Methods

Evaluation of Munich's City Development Planning

Case Study and Document Selection

The just recently adopted renewal of the city development plan is a milestone in the city development of Munich as it explicitly expresses the cities' intentions for the next decade, setting the stage for a range of adjacent plans, programmes and initiatives (Stadtverwaltung, 2024). The plan is furthermore provided in the city's geoportal, which makes it particularly suitable for an evaluation by digital means. Likewise, the JUSTNature justice mapping was provided in a digital format. The comparison of both documents is also facilitated by their scale, which is precise at the neighborhood level.

To this end, a plan evaluation methodology was developed, aiming to allow for a standardized procedure to evaluate rationales and siting of interventions planned within the city development plan of Munich. The methodology follows recent plan evaluation methodologies that employ both quantitative and qualitative methods (Grabowski et al., 2023; Hoover et al., 2023; Oliveira & Pinho, 2009). First, interventions planned within the city development plan are analyzed by qualitative means regarding their potential in answering the justice challenges. Secondly, the siting of each intervention is analyzed in a QGIS processing algorithm to understand whether the siting of intervention complies with the demands of each neighborhood detected in the Justice Mapping.

JUSTNature Justice Challenges

To gain a better understanding of the challenges arising from the justice mapping, each of the nine ecological and seven socio-demographic indicators is mapped with the 10% and 25% quantiles of the lower or upper boundary, depending on whether low or high values indicate poor performance, respectively. By overlaying the maps, conglomerations of poorly performing neighborhoods can be identified and thereby understood which areas are particularly challenged in terms of socio-ecological justice.

STEP Codebook

The STEP2040 is composed of seven overarching goals, for each of which several strategies were developed. The strategies are operationalized by interventions. The city development plan comprises in total 7 Goals, 20 Strategies, and 61 Interventions, whereas some interventions are used in several strategies. The STEP2040 Codebook gives an overview of the goals and associated strategies and interventions. It further outlines why some of the interventions were excluded from further investigation - either due to vagueness and hence difficulties in verifiability with respect to the justice indicators or due to unsuitability to cater to the challenges arising from the justice mapping. Two out of the seven goals were omitted completely since they do not comprise GI interventions.

Plan Evaluation Screen

The evaluation screen determines the criteria on which the city development plan interventions are evaluated, hence given a weight according to their effectiveness in tackling each justice challenge.

Level 0 - intervention is unsuitable (Weight: 0)
Level 1 - intervention indirectly impacts the justice dimension, but the impact is undirected (Weight: 0.2)
Level 2 - intervention directly impacts the justice dimension, mitigating the challenge, not eliminating the challenge (Weight: 0.5)
Level 3 - intervention directly impacts the justice dimension and has the capacity to reduce justice challenge to an uncritical level (Weight: 1)

Evaluation of Spatial (Mis)matching

To assess whether the siting from the city development plan complies with the justice challenges derived in the first step, the occurrence of each intervention (yes/no) in each neighborhood is checked by a processing algorithm in QGIS which was developed for this study. The algorithm gives a binary output for the presence/ absence of each intervention in each neighborhood based on an image classification of the single intervention layers provided by the geoportal of Munich. The table with the binary values for each neighborhood for each intervention is then multiplied by the weights determined from the Plan Evaluation Screening for each justice dimension. The values of all interventions for each neighborhood are then summed up, leading to a final value as the percentage to which each justice dimension is addressed by the amount and type of intervention for each neighborhood. The percentages are mapped out for each justice dimension and can finally be brought into direct comparison with the justice challenges identified in the first step.

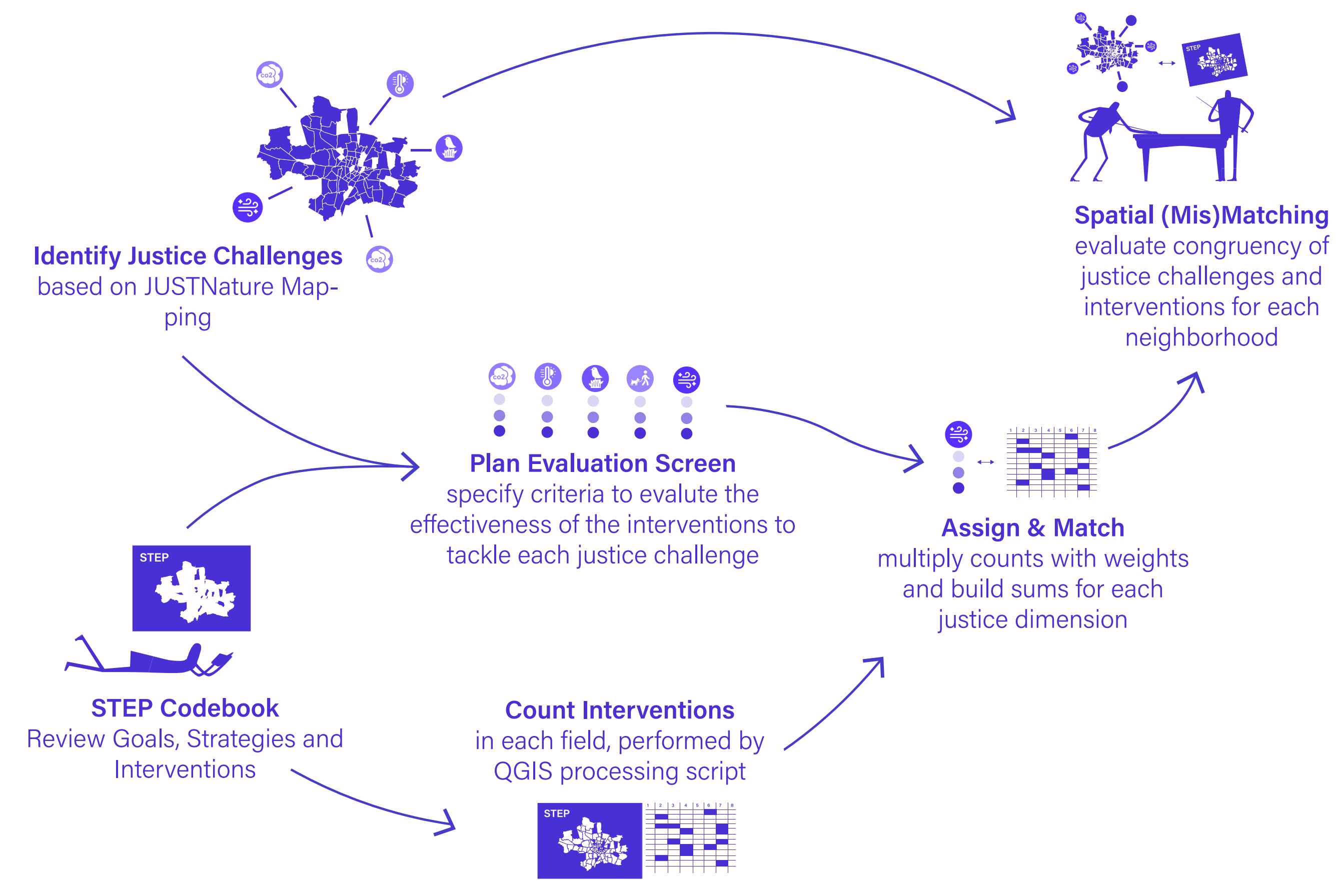

FIGURE 02: WORKFLOW FOR STEP2040 PLAN EVALUATION

3.1 Justice Assessment with JUSTNature Mapping

Figure 03: JUSTNature Project. Gantioler et al. (2023)

3.1.1 JUSTNature Justice Challenges

The JUSTNature Approach

The JUSTNature project set out in 2021, funded by the EU H2020 Grant, seeking to activate nature-based solutions (NbS) in cities to enable just transition to low-carbon cities. Building on the principle of the right to ecological space, JUSTNature wants to ensure fair access to environmental benefits, ecological spaces, clean air, and thermal comfort for human health and well-being, regardless of socioeconomic status. The project emphasizes particularly the relation to climate change mitigation and reducing greenhouse gas emissions. To do so, JUSTNature developed city profiles of selected pilot cities, one of them being Munich, to characterize the cities with respect to their socioeconomic-environmental equity performance. Out of nine ecological-justice indicators and seven socio-demographic justice indicators provided by JUSTNature, eight ecological and four socio-demographic indicators as displayed in figure 04 were used for the analysis. The ecological indicator "soil sealing difference between 2018-2022" was omitted due to a focus on the status-quo assessment in this work. The socio-demographic indicators "car density", "migration", and "unemployment" were not considered due to their limited informative value in predicting socio-demographic vulnerability as discussed in chapter two. This is supported by the results of the correlation analysis as displayed in table 02 that shows that income is strongly correlated with the amount of foreign population, as well as unemployment.

The selected indicators were then used to characterizes each neighborhood with regard to the twelve indicators. The resulting maps form the demand side of the analysis, hence make spatially explicit the neighborhoods with most environmental and socio-demographic challenges.

	Population Density	Aging Index	Foreign Population	Families with children	Income
Families with children	-0,47				
Unemployed			0,86		-0,77
Income		0,33	-0,61		
Car Density	-0,55			0,75	

TABLE 02: CORRELATION ANALYSIS OF SOCIO-DEMOGRAPHIC INDICATORS. ADAPTED FROM GANTIOLER ET AL. (2023)

Ecological Indicators:

FFH-Inclusion
Vegetation Quality
Betweenness centrality/ Connectivity

Air Quality Justice
PM2.5 concentration (Ug/m³)
Areas of Air Quality Risk (%)

Carbon Justice
Carbon Absorption Vegetation (ton/m²)
Carbon Emission Building (ton/m²)

Thermal Justice
Heat Stress Zones

Spatial Justice
Accessability (Walkability Index)

Assessment Method:

Landscape structure (Connecitvity) is evaluated using land cover maps derived from multispectral satellite imagery. Protected areas are identified using local geodatabases.

The air pollution risk of exposure is calculated using a combination of digital surface models, road network data, and traffic volumes.

Carbon emissions from building cooling and heating are determined using building cooling and heating density data. Carbon removal by vegetation is estimated using digital surface models and land cover maps.

Heat stress zones and surface urban heat islands are assessed using land surface temperature time-series data.

Accessibility to green areas within 800 m (10 minutes) is calculated using green urban area data (Urban Atlas LULC 2018) and road networks from local geodatabases.

Socio-demographic Indicators:

Population Density (Inhab/km2)

Aging Index

Families with children (%)

Income(EUR/inhab)

FIGURE 04: SOCIO-ECOLOGICAL JUSTICE INDICATORS. FROM GANTIOLER ET AL. (2023)

3.1.2 Socio-ecological Vulnerability

Standardization of Indicators

To ease the interpretation of the results, the indicators were standardized with a k-score standardization, also known as modified z-score standardization, using the following formula (Tamalunas, n.d.; Wolf & Best, 2010):

$$K_i = \frac{x_i - median(X)}{median(|x_i - median(X)|)}$$

As the histograms and boxplots in figure 1 and 2 in the Appendix show, most indicators are not normally distributed and have outliers (Wooldridge, 2016). The modified z-score standardization was hence chosen as it generally provides a more balanced and resistant view compared to the normal z-score standardization, avoiding the heavy influence of outliers and being more robust to skewness (Tamalunas, n.d.; Wolf & Best, 2010). Since each indicator is therefore centered around its own median, the quartiles indicate relative shifts in distribution.

Thermal Stress

The thermal stress values show a left-skewed distribution, with most values centered around zero but a noticeable tail extending toward -4. This suggests that while most neighborhoods in the city experience mild to moderate thermal stress, there are some neighborhoods with significantly lower stress levels (in the city center close to the park Englischer Garten and in the perihperal areas that connect to the green belt). The interquartile range (IQR) from -0.84 to 0.54 indicates that 50% of the data falls within this range, showing a moderate spread. The fewer extreme positive values compared to negative ones suggest that high thermal stress is less extreme or widespread than low-stress neighborhoods. The mitigating role of the river Isar becomes evident in the mapping, as no neighborhoods in direct proximity to the river are affected by extreme stress.

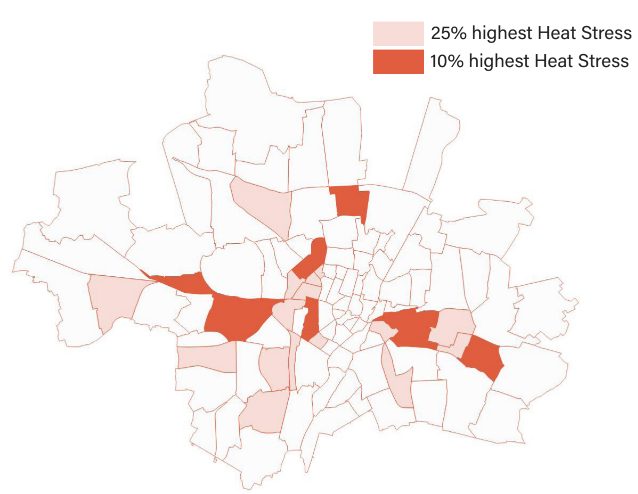

Figure 05: Heat Stress. Data from Gantioler et al. (2023)

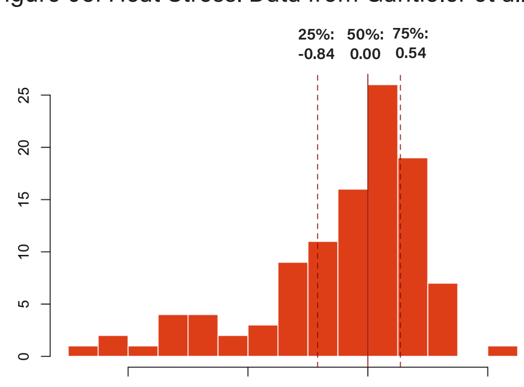

Figure 06: Heat Stress Distribution with Quartiles. Data from Gantioler et al. (2023)

DATA AND METHODS

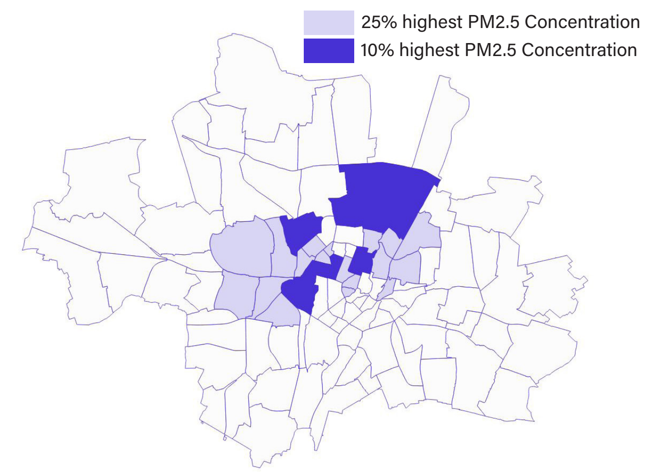

Figure 07: PM2.5 Concentration. Data from Gantioler et al. (2023)

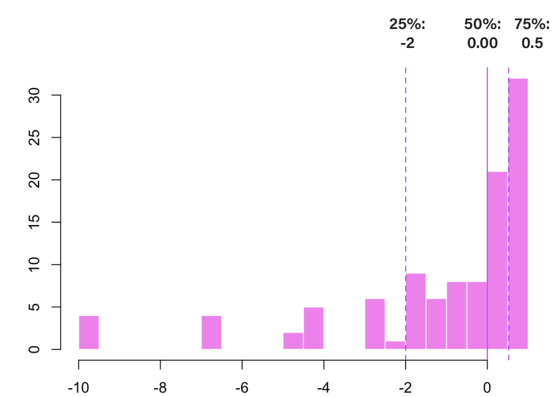

Figure 08: Pm2.5 Distribution with Quartiles. Data from Gantioler et al. (2023)

PM2.5 Concentration

The PM2.5 concentrations exhibit a strongly left-skewed distribution, indicating that while most areas have relatively low particulate matter levels, a minority experience substantially elevated pollution exposure.

Air Quality Risk Areas

The distribution of air quality risk is more symmetric, reflecting a broader, yet uneven spatial pattern of vulnerability.

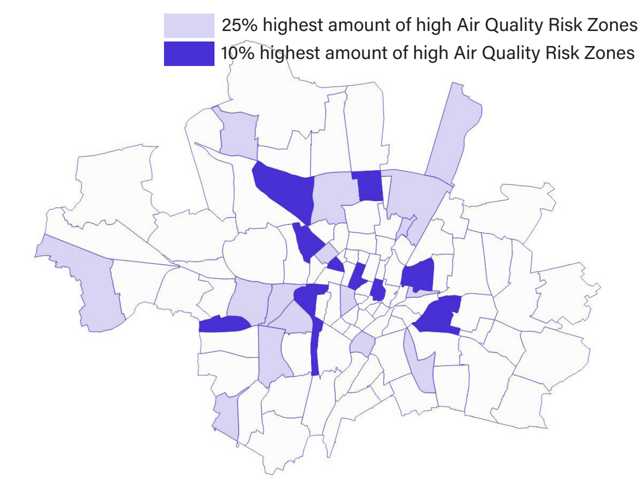

Figure 09: Areas with high Air Quality Risk. Data from Gantioler et al. (2023)

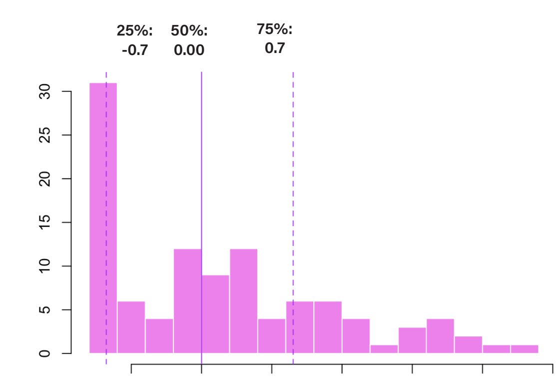

Figure 10: Areas with high Air Quality Risk Distribution with Quartiles. Data from Gantioler et al. (2023)

Green Space Connectivity

The IGR between Q1 and Q3 (from -0.67 to 1.74) of the green space connectivity indicator suggests a noticeable variability in green space connectivity across the different neighborhoods. The positive upper quartile and a lower quartile closer to zero suggest that there are more neighborhoods with higher-than-average connectivity than those with extremely low connectivity. This is congruent with the boxplot displayed in the Appendix, as a few neighborhoods show significantly higher values. These neighborhoods are typically cin the city center, close to the Englischer Garten (east of the river Isar). The highest value (fid 43) has been removed before the standardization, as it would have distorted the distribution too much.

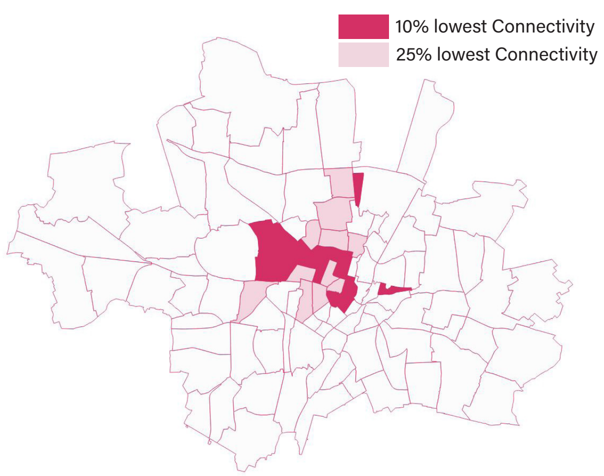

Figure 11: Connectivity of Green Spaces. Data from Gantioler et al. (2023)

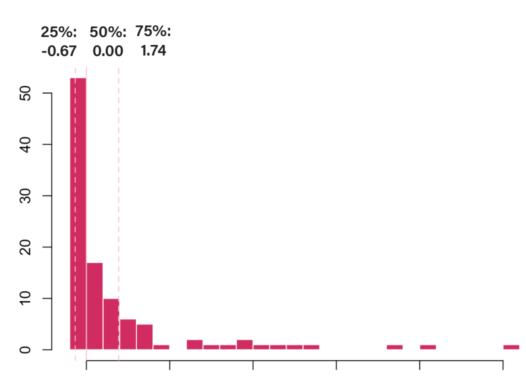

Figure 12: Green Space Connectivity Distribution with Quartiles. Data from Gantioler et al. (2023)

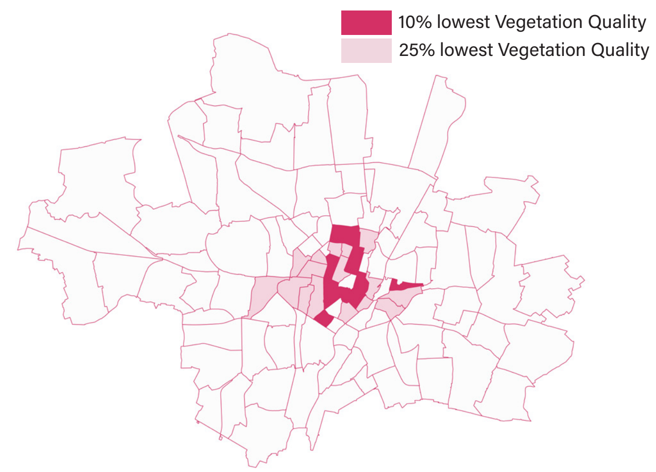

Figure 13: Vegetation Quality. Data from Gantioler et al. (2023)

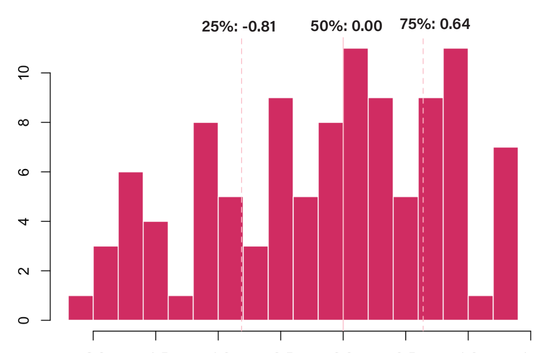

Figure 14: Vegetation Quality Distribution with Quartiles. Data from Gantioler et al. (2023)

Vegetation Quality

The distribution of the vegetation quality indicator is centered around the median with no extreme skewness. Compared to green space connectivity, the variation in vegetation quality appears to be somewhat smaller, as the upper quartile (0.64) does not reach as high as the value in the connectivity dataset.

Carbon Absorption by Vegetation

Both carbon absorption by vegetation and emissions from buildings exhibit right-skewed standardized distributions (P25 = -0.6, P75 = 1.0), indicating that while most areas cluster around the mean, a subset of zones experience significantly elevated emissions or absorption capacities.

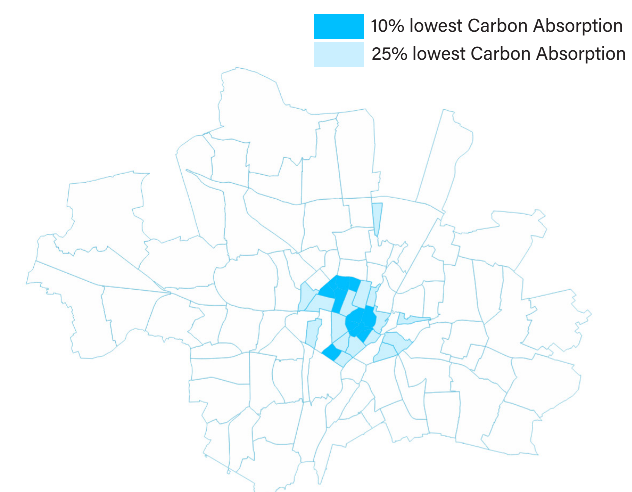

Figure 15: Carbon Absorption Vegetation. Data from Gantioler et al. (2023)

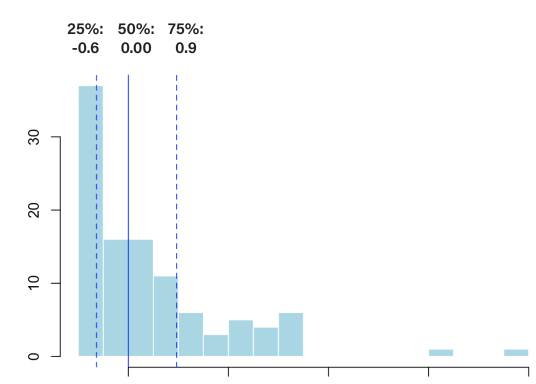

Figure 16: Carbon Absorption Distribution with Quartiles. Data from Gantioler et al. (2023)

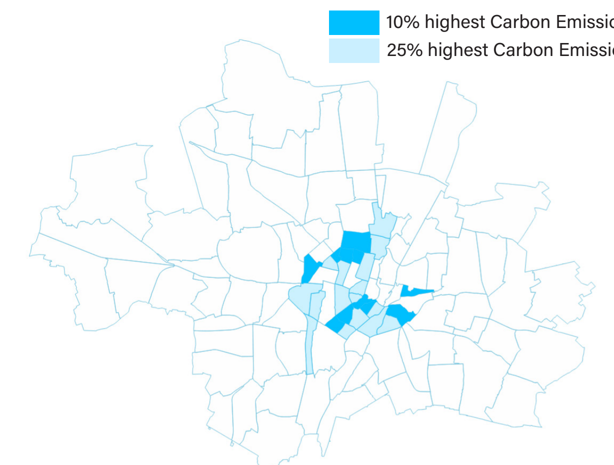

Figure 17: Carbon Emission Buildings. Data from Gantioler et al. (2023)

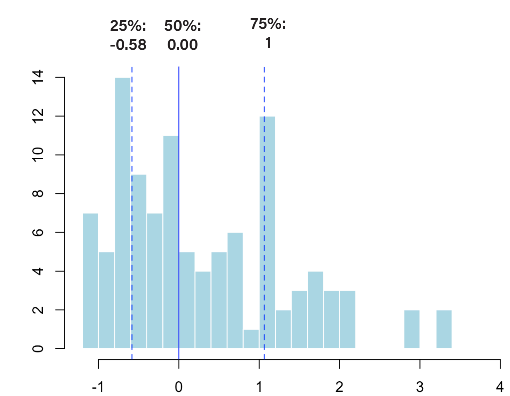

Figure 18: Carbon Emission Distribution with Quartiles. Data from Gantioler et al. (2023)

Green Space Accessability

The distribution of green space accessibility indicates a left-skewed pattern, with the 25th percentile at -0.9 standard deviations, suggesting that a substantial share of urban areas, notably in the peripheral areas of Munich, experience significant deficits in walkable access to green spaces. The strong patterns of low accessability in the outer areas likely stems from the assessment methods, in which only the Urban Green Areas Class was considered from the Copernicus Urban Atlas. Other types of green areas, as i.e. Arable Land and Forest that surround the city, are therefore not considered in this analysis.

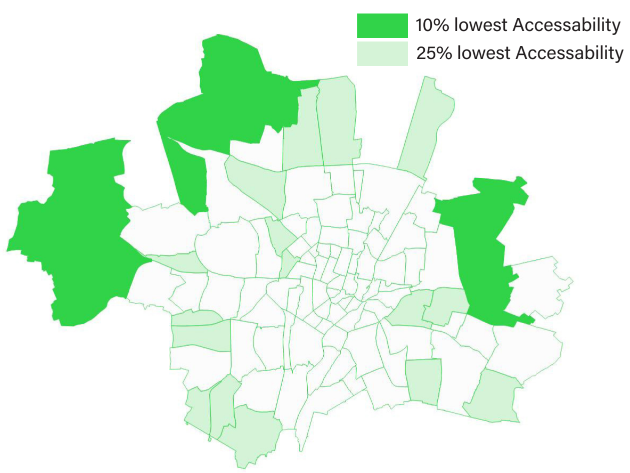

Figure 19: Urban Green Space Accessibility. Data from Gantioler et al. (2023)

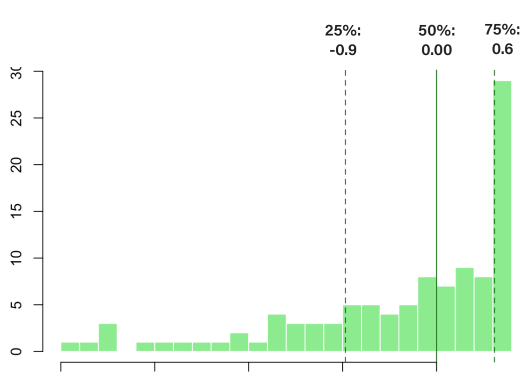

Figure 20: Green Space Accessability Distribution with Quartiles. Data from Gantioler et al. (2023)

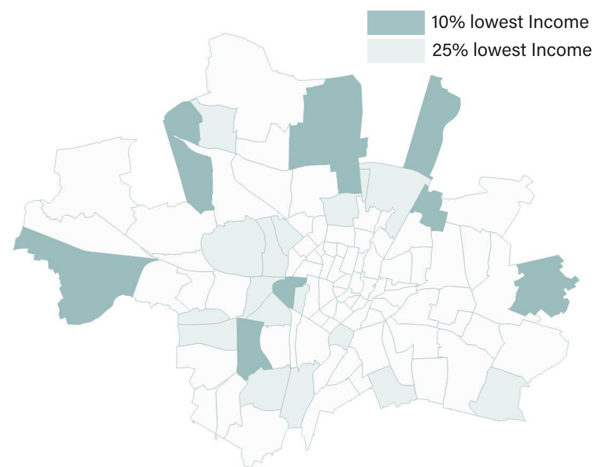

Figure 21: Income. Data from Gantioler et al. (2023)

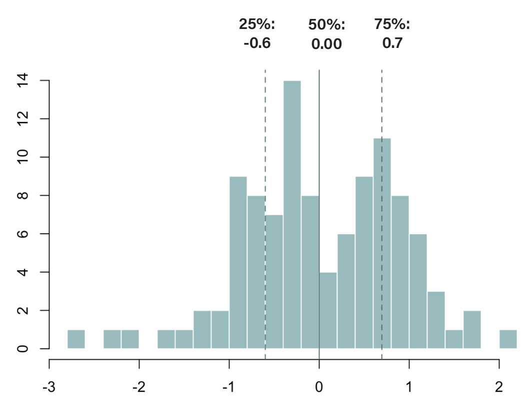

Figure 22: Green Space Accessability Distribution with Quartiles. Data from Gantioler et al. (2023)

Income

Most neighborhoods are near the median, with slightly more variation on the wealthier side. High-income areas are somewhat more distinct, while low-income areas cluster closer to the middle, meaning even the poorest areas aren't drastically below the median. This suggests moderate income inequality. The spatial distribution is quite distinct, as there are no low-income housholds neighborhoods in the city centre, wheras neighborhoods with a high amount of low income households are disproportionally more often located in the peripheral areas, as well as in the northern and western parts of Munich.

Aging Index

The Aging Index is almost symmetrically distributed, with areas having notably younger population and areas with notably older population, suggesting that older adults are more concentrated in certain neighborhoods. The mapping suggests that the neighborhoods in the northern parts of Munich as well as in the city center have a distinctively younger population.

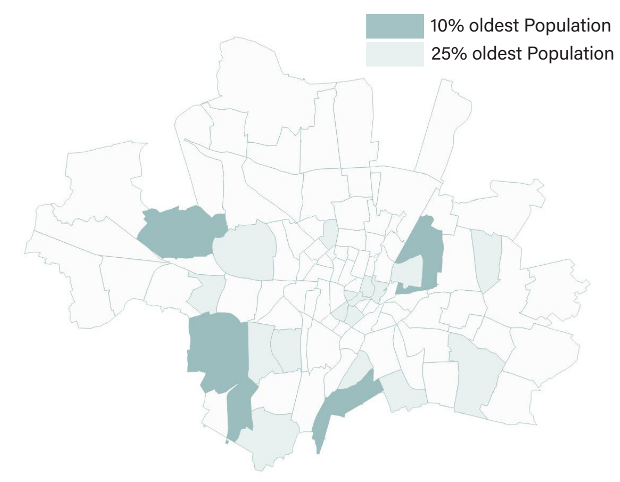

Figure 23: Aging Index. Data from Gantioler et al. (2023)

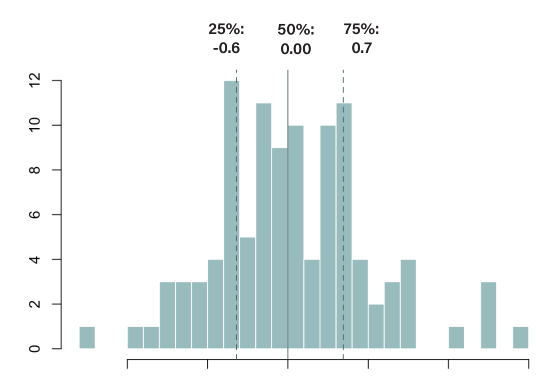

Figure 24: Green Space Accessability Distribution with Quartiles. Data from Gantioler et al. (2023)

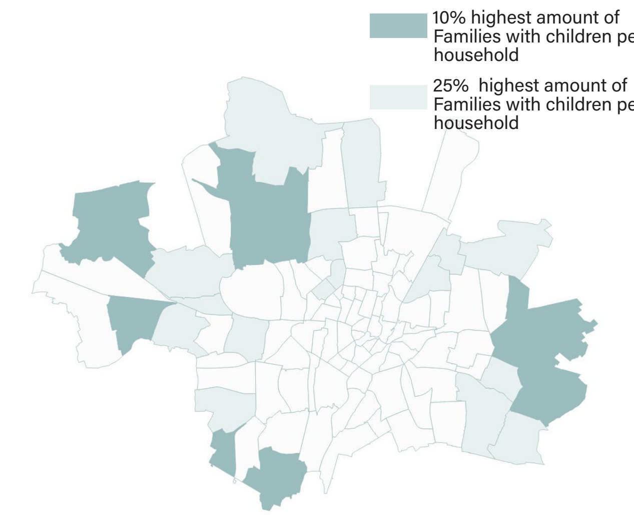

Figure 25: Families with Children. Data from Gantioler et al. (2023)

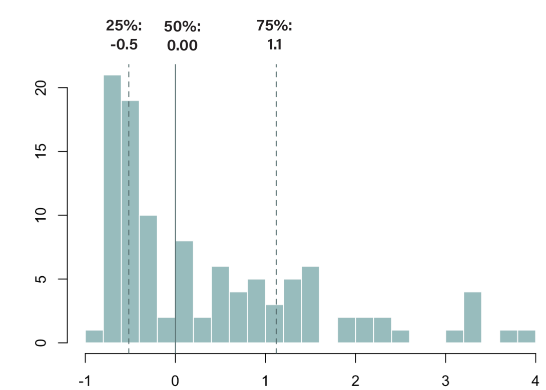

Figure 26: Green Space Accessability Distribution with Quartiles. Data from Gantioler et al. (2023)

Families with Children

A minority of neighborhoods have significantly higher concentrations of families with children. The lower end is less extreme, indicating that areas with fewer children are not drastically underrepresented. The spatial distribution of the indicator is quite straighforward, as all neighborhoods with a higher amount of families with children are located towards the peripheral areas of Munich, with no neighborhoods in the inner city.

Population Density

The distribution of population density is strongly righ-skewed, suggesting that there are a verw highly dense neighborhoods that stand out dramatically. Most other areas have low to moderate density with limited variation below the median. This means that Munich has a few very dense hotspots, and many moderately to low-density zones. This becomes evident in the mapping, as highly populated zones - with the exception of Neufreimann in the North - are exclusively in the inner city.

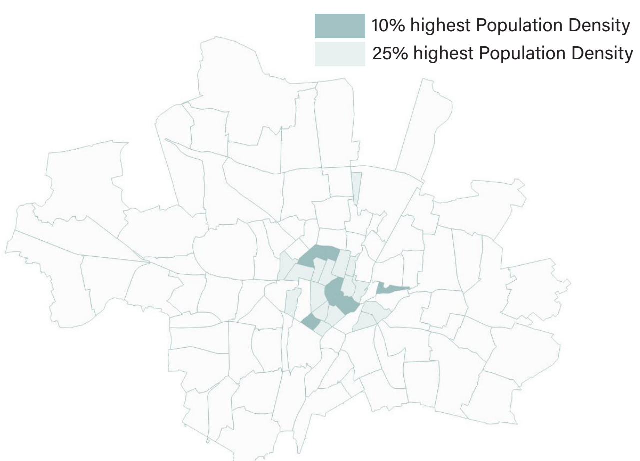

Figure 27: Population Density. Data from Gantioler et al. (2023)

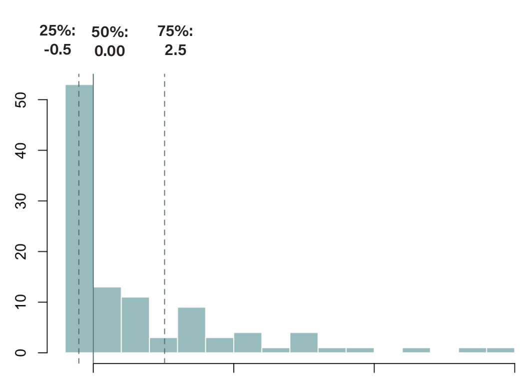

Figure 28: Green Space Accessability Distribution with Quartiles. Data from Gantioler et al. (2023)

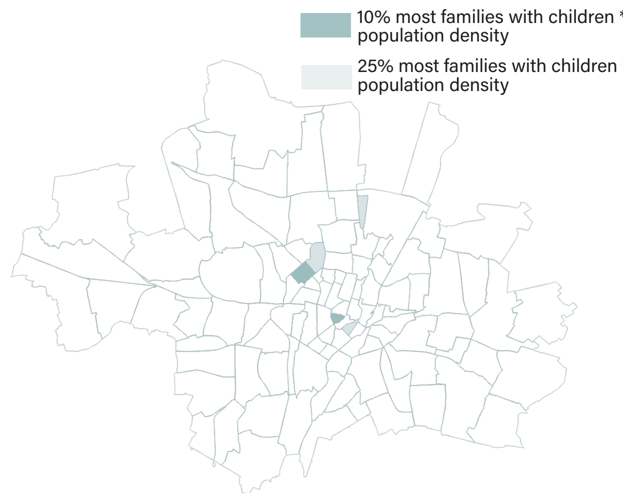

Figure 29: Families with Children multiplied by Poplulation Density. Data from Gantioler et al. (2023)

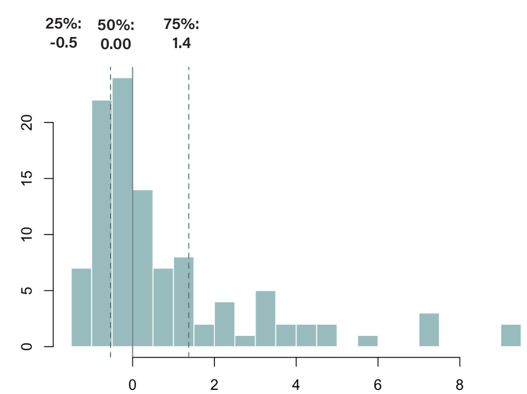

Figure 30: Green Space Accessability Distribution with Quartiles. Data from Gantioler et al. (2023)

Families with Children * Population Density

By multiplying the indicators families with children with the population density, neighborhoods where both population density and families with children are high are amplified. The 75th percentile is 1.4, higher than either variable on its own, suggesting concentration zones. These "family-dense urban hubs" are found mainly in or close to the inner city. The lower end (Q25) matches both individual indicators' values, meaning that low-density and few children areas are common but not extremely distinct from the median.

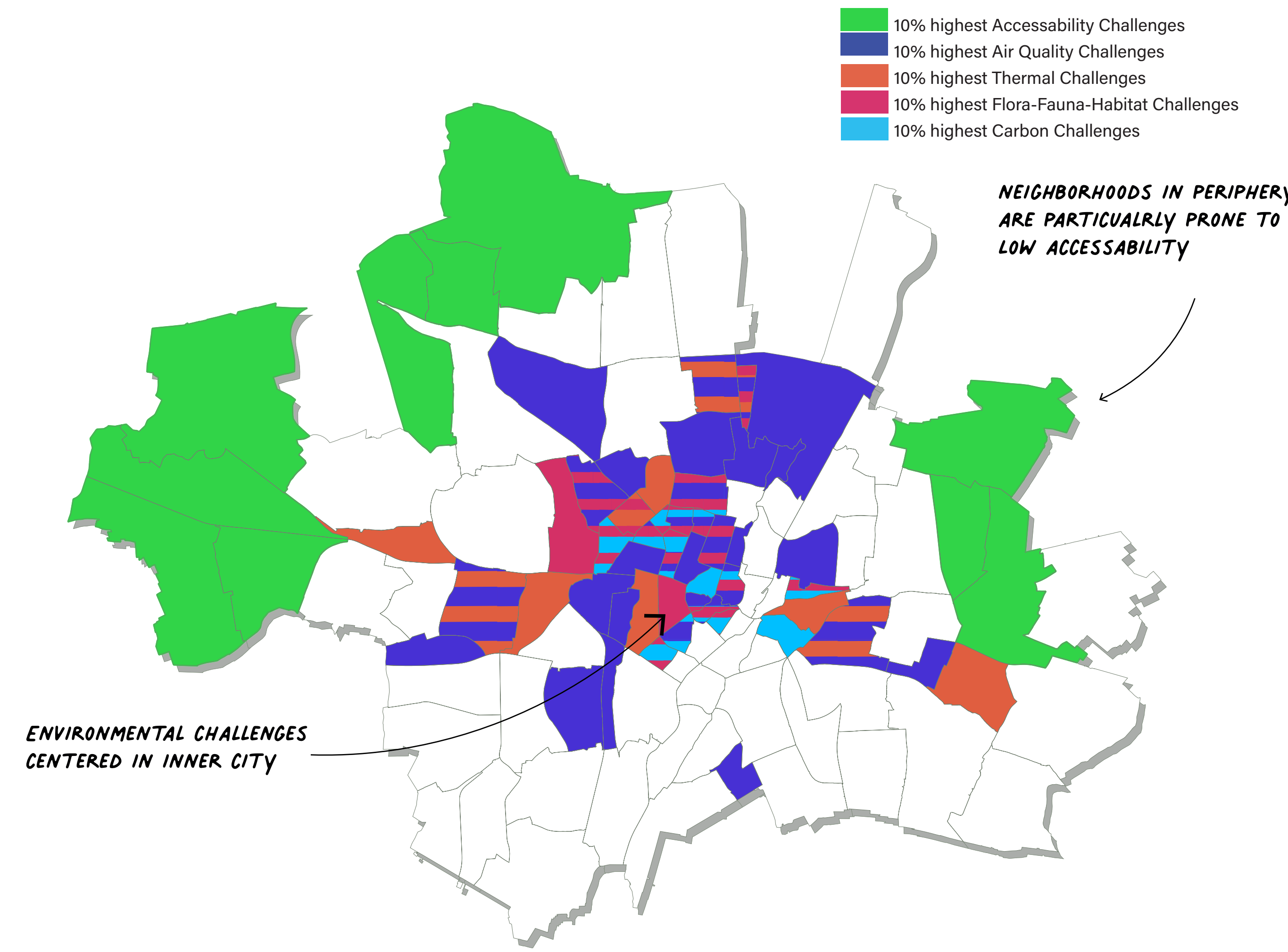

Figure 31: Justice Challenges Overview. The marked neighborhoods have the lowest performance in terms of the considered environmental dimensions. Data from Gantioler et al. (2023)

Identifying Hotspots from JUSTNature Mapping

It becomes evident that there is a strong trend in both the socio-demographic and ecological indicators based on the neighborhood's proximity to the city center. Neighborhoods in the city center are mostly composed of high-income, childless households with high accessibility to urban green spaces, although of low quality and not well connected. Furthermore, many of the city center neighborhoods have a low rate of carbon absorption and high carbon emissions, hinting towards a carbon justice challenge. Neighborhoods in the periphery seem to be only severely affected by low accessibility of green spaces. There are no signs of thermal, air quality, or carbon justice issues. The neighborhoods in between show a more diverse behavior, as some are affected by several justice dimensions and others are affected by none. Generally, they have a significantly lower population density, a higher Aging Index and lower income. In all of these neighborhoods, the vegetation quality, carbon absorption, and connectivity are above average. Some neighborhoods in this area exhibit quite clearly justice challenges due to the bad accessibility of green spaces coupled with a high amount of heat stress zones and air quality risk.

One aspect that stands out is the shift in which neighbourhoods are considered to be underperforming: While the city centre stands out as the most critical neighbourhood when looking solely at ecological indicators, this almost disappears when social challenges are added, and criticality shifts to the peripheral neighbourhoods.

3.2 Plan Evaluation of STEP2040

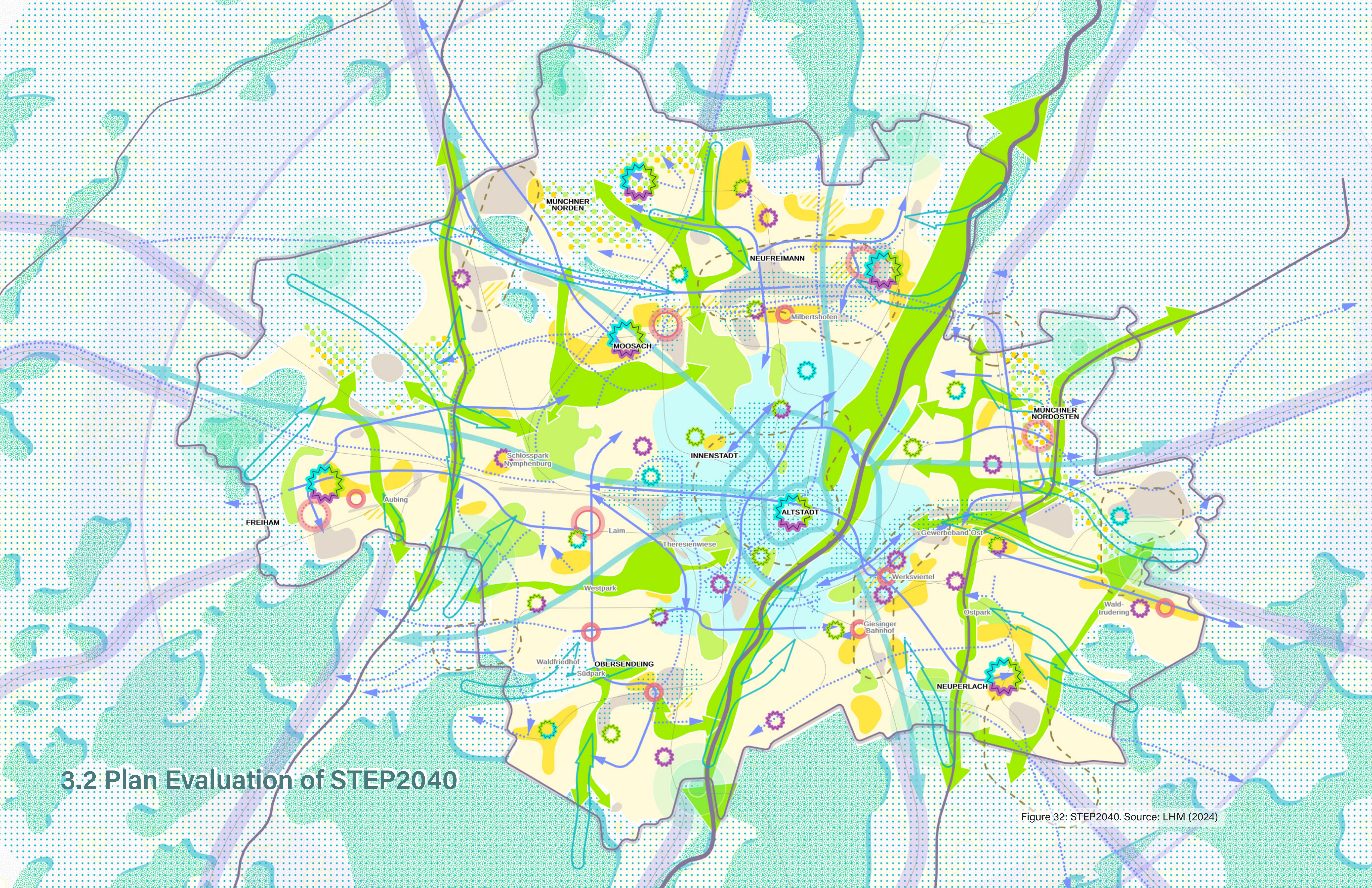

Figure 32: STEP2040. Source: LHM (2024)

3.2 STEP Codebook

> "That Munich will change its look is [...] certain. The question is, how will we succeed in meeting the needs of all social groups in these times of radical change?"
>
> (Department of Urban Planning and Building Regulation Munich, 2013, p. 8)

Development Process

The new urban development plan (STEP2040) was adopted by the city council on October 2nd, 2024, and replaces the planning strategy from 1983. Its main goal is the sustainable urban development and the "balancing of social, ecological and economic interests for a city in equilibrium" (Stadtverwaltung, 2024). The urban development plan was developed in a multi-year, broad-based participatory process, bringing together a diverse range of stakeholders, including citizens, experts, political actors, and civil society organizations. A citizens' council was established to formulate recommendations for the city council. Concurrently, public participation formats, including workshops (i.e. "Stadtmacher*innen-Konferenz"), conferences, and digital platforms, were made available, through which thousands of citizens submitted proposals. (Stadtverwaltung, 2024)The online platform "München Mitdenken" served as a pivotal channel for idea collection and discussion (facebook, n.d.; "Lebensqualität München - Beteiligung in der Werkstadt München," n.d.). Munich's City Council, specifically the Committee for Urban Planning and Building Regulations, defined the guidelines for the plan and approved the draft. The Department of Urban Planning and Building Regulations coordinated the entire planning process and ensured that the targets set were met. Experts from the fields of climate protection, mobility and urban design provided analyses and scenarios that were incorporated into the plan. (Stadtverwaltung, 2024)

Goals, Strategies and Interventions

A first qualitative analysis was undertaken with a word occurrence count done by Atlas.ai. Based on the word occurrence count, key words that represent the plan's core ideas were selected and ranked according to their occurrence. This review gives a first impression of the focus in the documentation adjacent to the plan. Expanding this word count analysis by relating the key words to the justice dimensions, the written part seems to concentrate slightly more around thermal and carbon justice dimension. Key words relating to more than one justice dimension were excluded; words that occurred at least two times were included.

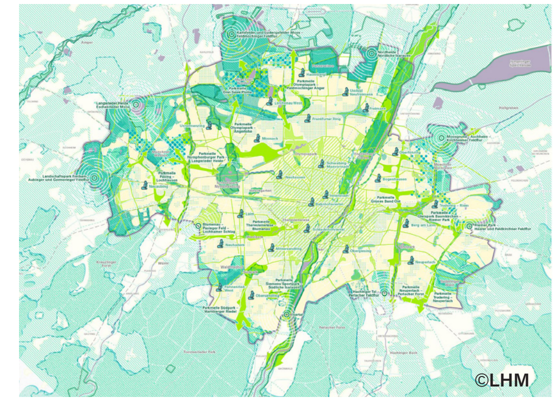

Figure 33: green and connected open space

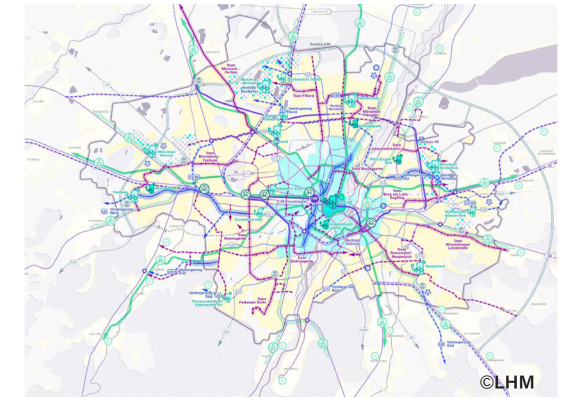

Figure 34: efficient, reliable and climate-neutral mobility

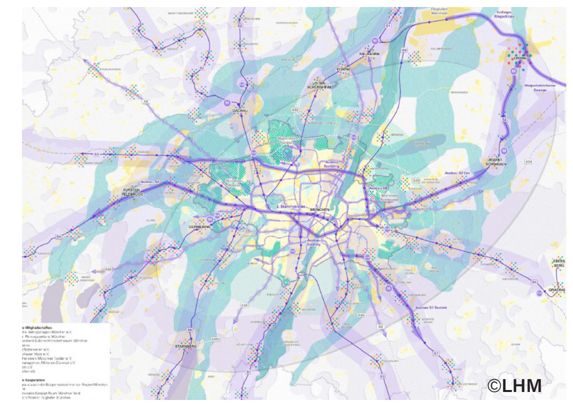

Figure 35: partnership-based development of the city region

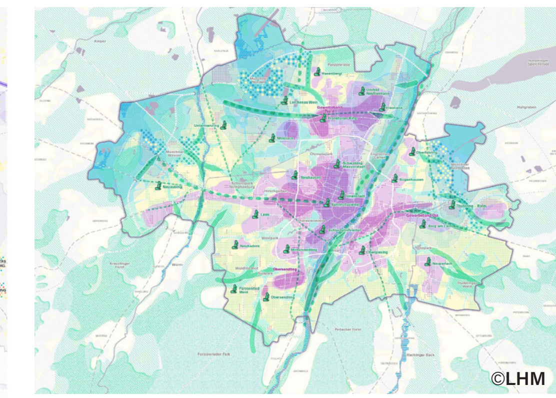

Figure 36: Climate-adapted landscapes and settlement areas

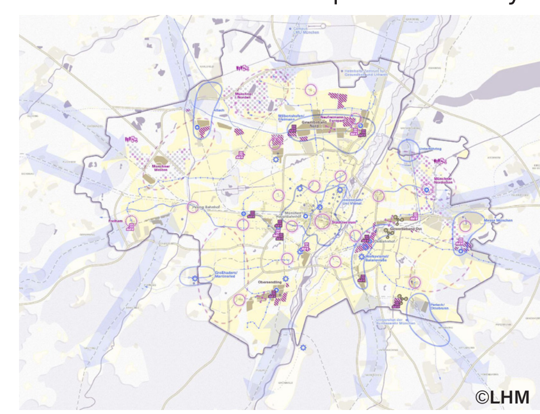

Figure 37: Innovative and productive economy

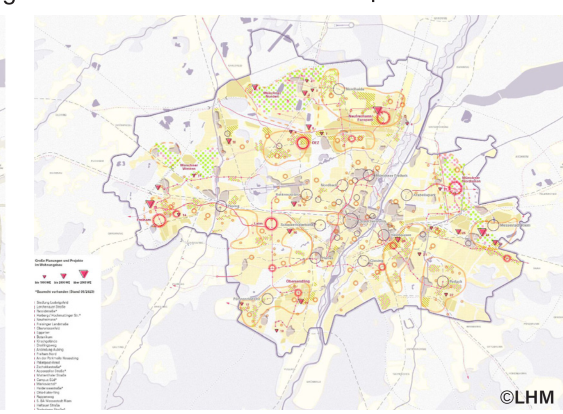

Figure 38: Strong residential districts and sustainable urban development

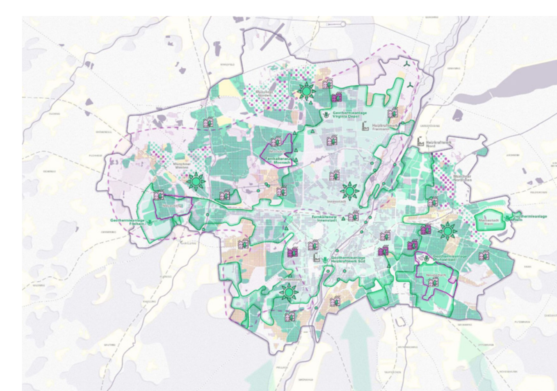

Figure 39: climate-neutral neighborhoods and renewable energies

Defining GI Interventions: What does it take to be one?

To assess the effectiveness of GI Interventions in the city development plan of Munich, it must first be clarified which measures are considered GI planning interventions, as opposed to conventional or grey infrastructure planning interventions. As Grabowski et al. (2022) point out, GI planning concepts are conceived differently depending on the national context. While GI planning often refers to stormwater management in the US, the European perspective on GI is strongly rooted in landscape and park systems or garden city concepts.

The EU defines GI as "a strategically planned network of natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services, while also enhancing biodiversity". Following this definition, only gray and mono-functional infrastructure is explicitly excluded as GI intervention. To better distinguish the facets in between green-grey solutions, the GI planning principles established by Hansen & Pauleit (2014) are used as criteria to determine whether a STEP2040 intervention was considered as GI intervention. Only if all of the following planning principles are met, the intervention is considered as GI intervention: Integration, Multifunctionality, Connectivity, Multi-scale approach, Multi-object approach. From the 61 interventions, 13 were considered spatially explicit GI interventions that were included in the analysis.

Key Word Occurence

Freiraum (Open space)	15
Klimaanpassung (Climate adaptation)	10
Mobilität (Mobility)	10
Wohnraum (Housing)	5
Grün (Green)	8
Wirtschaft (Economy)	7
Erholung (Recreation)	6
Natur (Nature)	5
Lebensqualität (Quality of life)	5
Klimaschutz (Climate protection)	5
Infrastruktur (Infrastructure)	5
Siedlungsräume (Settlement areas)	4
Biodiversität (Biodiversity)	4
Energie (Energy)	4
Sozial/e (Social)	4
Vielfalt (diversity)	4

Key Word Occurence by Justice Dimension

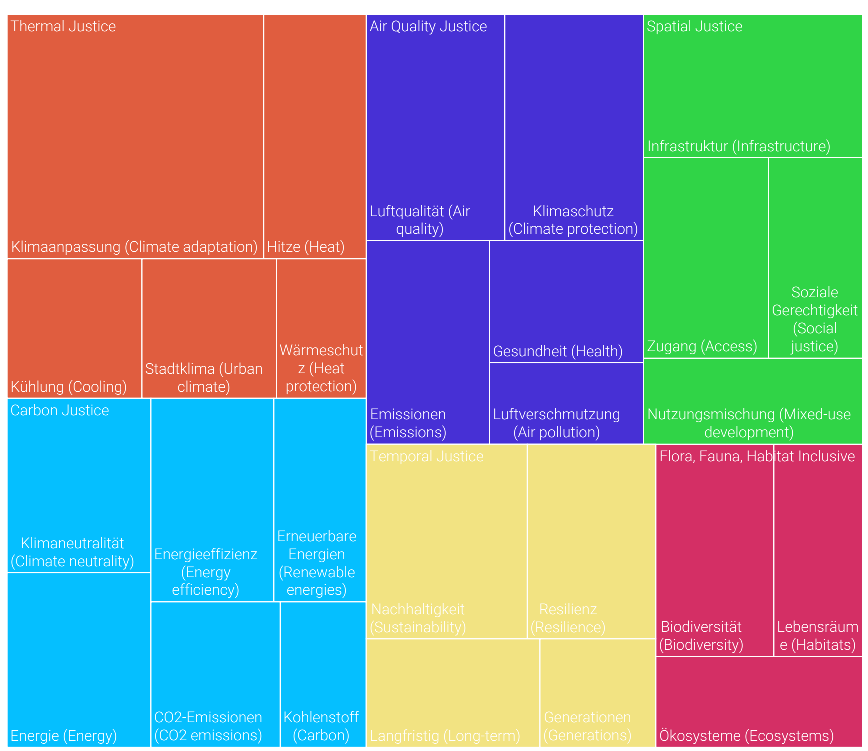

Figure 40: Key word Occruence by Justice Dimension. Data from Stadtverwaltung, L.m. (2024)

STEP Goal	STEP INTERVENTION	Integration	Multifunctionality	Connectivity	Multi-scale approach	Multi-object approach	Reason for Exclusion
Open Space	Open space neighborhood concepts	☑	☑	☑	☑	☑	
	focus areas green infrastructure	☑	☑	☑	☑	☑	
	streets as open spaces / car free old town	☑	☑	☑	☑	☑	
	Park Miles	☑	☑	☑	☑	☑	
	Bigger Parks/ Open Spaces						no intervention
	Open Space Axis	☑	☑	☑	☑	☑	
	Green belt						spatially unspecific
	Inter communal landscape concepts						no intervention
	protected areas	☑	☑	☑	☑	☑	
	biotope protection	☑	☑	☑	☑	☑	
	areas with ffh-goals	☑	☑	☑	☑	☑	
	climate resilient forest development	☑	☑	☑	☑	☑	
Mobility	New bus lanes, subway, suburban rail and streetcar lines, more frequent services	☐	☐	☑	☐	☑	strong focus on grey infrastructure; no hint towards integration with green infrastructure
	public transportation nodes (connection rail traffic and bycicle lanes)	☑	☑	☑	☑	☑	
	Mobility concepts	☐	☑	☑	☐	☐	enabler of GI, not GI itself
	Car and bike sharing offers (regional)						no intervention
	High-speed cycle network	☐	☑	☑	☑	☐	enabler of GI, not GI itself
	Bicycle parking facilities	☐	☑	☑	☑	☐	no intention towards integration with green infrastructure
	Mobility Hubs (P&R)	☐	☐	☑	☑	☐	focus on commuter traffic (grey to grey infrastructure connection)
	High occupancy vehicle lanes	☑	☑	☑	☑	☐	focusing exclusively on grey traffic modes (bus & cars)
Climate Adaptation	Reduce areas with heat stress						unspecific: same as blue green
	nature-based rain water management	☑	☑	☑	☑	☑	
	Flooding areas						no intervention
	High Aquifer						no intervention
	Preserve cold air corridors and cold air development areas	☑	☑	☑	☑	☑	
	Preserve air exchange spaces	☑	☑	☑	☑	☑	
	preserve areas with high bioclimatic importance	☑	☑	☑	☑	☑	
Region	regional green corridors						technical issue Geoportal: empy layer
	Development settlement along public transport						technical issue Geoportal: empy layer
	development open space along public transport						technical issue Geoportal: empy layer
	landscape, settlement and open space						technical issue Geoportal: empy layer
	Mobility Hubs	☐	☐	☑	☑	☐	focus on commuter traffic (grey to grey infrastructure connection)
Climate Protection	energy from renewable sources	☐	☑	☐	☑	☐	no intention towards integration with green infrastructure
	integrated neighborhood concepts	☑	☑	☑	☑	☑	
	improvement energy efficiency buildings	☑	☑	☐	☑	☐	focus on energy-efficient refurbishment of the buildings via building materials
	rehabilitation areas with climate protection	☑	☑	☐	☑	☐	citizen participation by offering energy-saving consultations; no spatial intervention
	improve connection density in the district heating supply area	☐	☑	☑	☑	☐	focus on technical solution
	PV						spatially not defined yet
	suitable areas for decentralized heating	☐	☑	☐	☑	☐	focus on technical solution

TABLE 03: OVERVIEW STEP2040 GOALS & INTERVENTIONS FROM STADTVERWALTUNG, L.M. (2024) AND CRITERIA FOR CONSIDERATION AS GI INTERVENTION.

Determination of GI Intervention's effectiveness: Assigning Weights

To distinguish between different levels of effectiveness of the interventions to tackle a specific justice challenge, weights were assigned to each intervention for each justice dimension. This allows for comparison across areas, aiming to better differentiate which areas are getting more effective interventions. Since there is no exhaustive performance scoring of GI interventions or NBS solutions available, the weights were derived by the evaluation screen in table 05. The evaluation screen specifies rationales for each justice dimension that an intervention must meet to obtain a certain score. The scale ranges from 0-1, whereby 1 indicates that the sole implementation of that intervention has the potential to reduce the respective justice challenge to an uncritical extent in that neighborhood. This scoring aims to enable a nuanced understanding of each intervention's potential impact, facilitating prioritization and resource allocation for maximum justice outcomes.

Validation of weights

The weights were validated in two ways: First, the NBS performance assessment from Castellar et al. (2021) was consulted to check the congruency with their score. Castellar et al. (2021) summarized the four NBS catalogs URBANGREENUP (2018), UNALAB (2019), NATURE4CITIES (2020), and FAO (2016) and provided an online tool (https://icra.shinyapps.io/nbs-list/) from which the score of all NBS for the different urban challenges are available. For the derivation of the scores, the NBS from their study were matched with the corresponding intervention from STEP2040 as displayed in figure 8 in the appendix. Secondly, a sensitivity analysis using a scenario comparison was conducted. To that end, the baseline weighting derived from the prior steps was compared to an equal weighting scenario, in which all interventions that were considered relevant for a specific justice challenge were assigned a value of 1 and all others 0, and a no weights scenario, in which only the (non)existence of an intervention is considered, regardless of their relevance for a justice dimension. Figure 3-7 in the appendix shows the comparison of the scenarios by the difference in ranks that the neighborhoods take in each scenario. The change in ranks is low to moderate and the median is generally more balanced with the final weighting scheme.

Table 04 gives an overview of all STEP2040 interventions that were considered in the analysis with their respective score for each justice dimension.

STEP Goal	STEP INTERVENTION	Air Quality	Carbon	Thermal	FFH-Inclusion	Spatial
Open Space	Focus areas Green Infrastructure	0,5	0,2	0,5	0,2	0,2
	Streets as Open Spaces / Car Free old Town	1	0,5	0,2	0,2	0,5
	Park Miles	1	1	1	0,5	1
	Open Space Axis	1	0,5	0,5	0,5	1
	Protected Areas	0,2	0	0	0,2	0
	Biotope Protection	0,2	0	0	0,5	0
	Climate Resilient Forest	0,2	0,5	0	1	0
	Areas with FFH-Goals	0,2	0	0	1	0
Climate Adaptation	Nature-based Rain Water Management	0	0	0,2	0,5	0
	Preserve Cold Air Corridors and Cold Air Development Areas	0	0	1	0	0
	Preserve Air Exchange Spaces	0,5	0	0,2	0	0
	Preserve Areas with High Bioclimatic Importance	0	0	1	0	0
Climate Protection	Integrated Neighborhood Concepts	0,5	0,2	0,2	0,2	0,2

TABLE 04: STEP2040 CODEBOOK WITH WEIGHTING. STEP GOALS AND INTERVENTIONS FROM STADTVERWALTUNG, L.M. (2024)

Justice Dimension	Description of Indicator [1]	NBS Contribution [2]	Indicator	Level 0- unsuitable (0pt)	Level 1- indirect impact (0,2pt)	Level 2- direct impact (0,5pt)	Level 3- ideal (1pt)
Air Quality	Higher exposure to average values of air pollutants (e.g.,NO2, O3, SO2, CO and PM10 and PM2.5) among different groups of the population; taking into consideration procedural impacts on the distribution of an Air Quality Monitoring Network and potentially resulting blind spots	Key focus on urban trees, due to the short growing season in the northern region seems to be limited, the most relevant features are canopy density, foliage longevity and emission potential, the contribution may vary based also on the local conditions (e.g. canyons). Green walls and roofs on building enevelops can also be used as effective air pollution	PM2.5 Concentration Area of Air quality risk (low, medium, high)		intervention gives incentive to switch to lifestyle with lower amount of air polluting emissions produced	intervention reduces amount of pollutions in the air	intervention is sufficient to reduce air pollutants to uncritical level in the neighborhood
Carbon	Carbon justice refers to the responsibility for greenhouse gases (GHG) emissions, accountability for the distribution of the related environmental ills, and considerations on climate change mitigation potential of different ecosystems and their distribution across the city [1]. At the urban level this concerns different types of GHG – or carbon dioxide equivalent – (mainly CO2, CH4, NO2 and SF6). Regarding carbon generation, focus has been placed on the emissions related to building cooling and heating, since they constitute around half of the EU energy consumption	Key focus on trees (new), urban and peri-urban forests (protected & managed), grasslands and peatlands (restored & managed). Indirect impact of green roofs and facades on the energy consumption and thus GHG emissions of buildings, as well as of pocket-gardens and mini-forest on slowing down traffic	Carbon Absorption Vegetation		intervention reduces amount of grey infrastructure in favor of green	interventions increases amount of green, vegetated spaces	intervention creates/ supports green spaces with focus on plant health
			Carbon Emission Buildings		intervention gives incentive to switch to lifestyle with lower amount of carbon emitted	intervention reduces carbon emission	intervention is sufficient to bring emmited carbon levels close to zero
Thermal	Reduction of the inequitable distribution of extreme heat conditions and related risks across different areas within the same city and the vulnerable population	Vegetation at street level plays a key role in mitigating high temperatures through evapotranspiration and, in the case of trees and urban forests, the provision of shade. Horizontal greening also contributes to the improvement of thermal conditions, albeit with more limited effects at pedestrian level.	Heat stress zones		intervention reduces amount of grey infrastructure in favor of green; thereby preventing further increase in heat stress	interventions aiming at small-scale reduction of urban heat	interventions with wide scope of impact for active heat reduction
FFH-Inclusion	Flora-Fauna-Habitat refers to the extension of justice considerations to nonhumans that prioritizes the environment at the species-, individual-, or the ecosystem level [1]. This can refer to the unequal distribution of common environmental goods (like protected areas and elements with specific non-human value) and disturbances, and the uneven distribution of urban	A NbS framework inclusive to HFF in and for cities builds upon on the equitable distribution of environmental goods and bads, social–ecological interconnectedness, nature's agency and capabilities, and the broadening of representative and procedural justice principles. High importance given NbS's dominance as the interface of direct	Vegetation Quality		intervention reduces amount of grey infrastructure in favor of green	interventions aims at increasing amount of green, vegetated spaces	intervention targets creating/ support of green spaces with focus on plant health
			Betweenness centrality/ connectivity		intervention reduces amount barriers/ hurdles between green spaces	interventions aims at increasing amount of green, vegetated habitat patches	intervention targets creating/ support of connected green spaces
Spatial	Spatial justice refers to the distribution of environmental amenities and disamenities, such as socio-spatial segregation, sorting of urban population and gentrification impacted by the socioeconomic context, individual and social vulnerabilities [1]. Accessibility has been identified as the main indicator to provide the baseline information on possible disparity conditions within the urban area. It is recognized as an essential criterion to investigate	NbS can play a substantial role in the way the dimensions of social equity are considered, including spatial justice. → A key role is given to urban planning and the ability to manage trade-offs and conflicts, considering the space as a social area.	Accessibility urban green areas		increase in mobility offers; hence increase in possible modes to arrive at green spaces	reduction of barriers to reach and access green spaces	increase of green space; reduction of walking minutes to next urban green space

DETERMINES THE WEIGHT THAT IS GIVEN TO EACH INTERVENTION FOR THE DIFFERENT JUSTICE CHALLENGES

TABLE 05: PLAN EVALUATION SCREEN FOR WEIGHTING.

STEP2040 as quanfitied GI Intervention Maps

The resulting maps translate the strategic development plan into maps that quantify the green infrastructure intervention impact on the different ecological justice dimensions. The strong impact of the Park Miles interventions, especially around the river Isar, are evident for all dimensions. Differences in the intervention's impact are particularly visible in the 50-75% quantile which is prevailent mostly in the peripheral areas.

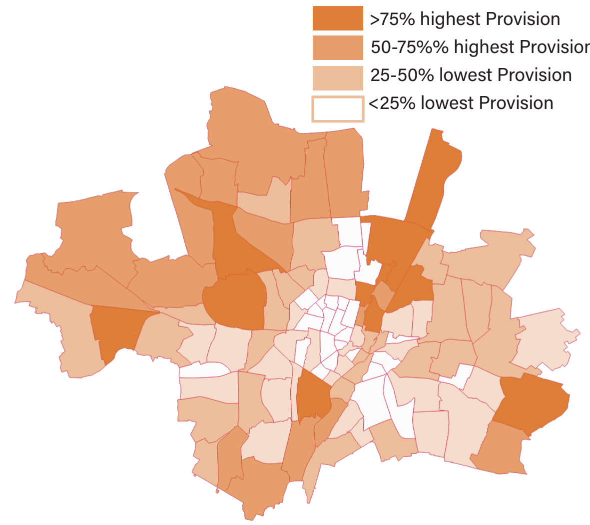

Figure 43: Flora-Fauna-Habitat GI Interventions. Based on data from Stadtverwaltung, L.m. (2024)

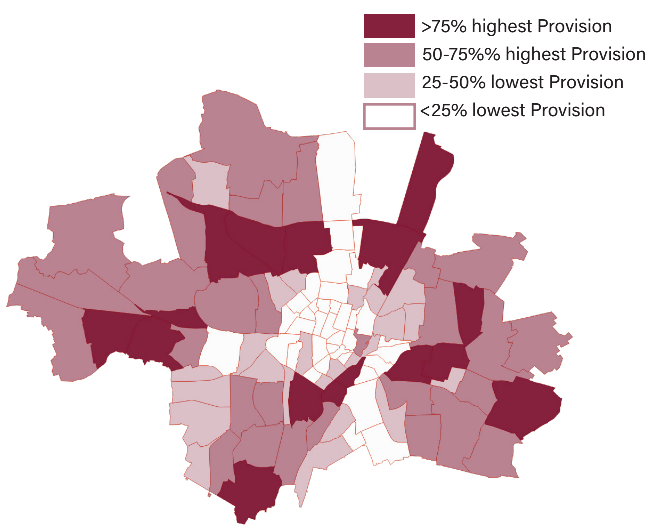

Figure 41: Thermal GI Interventions. Based on data from Stadtverwaltung, L.m. (2024)

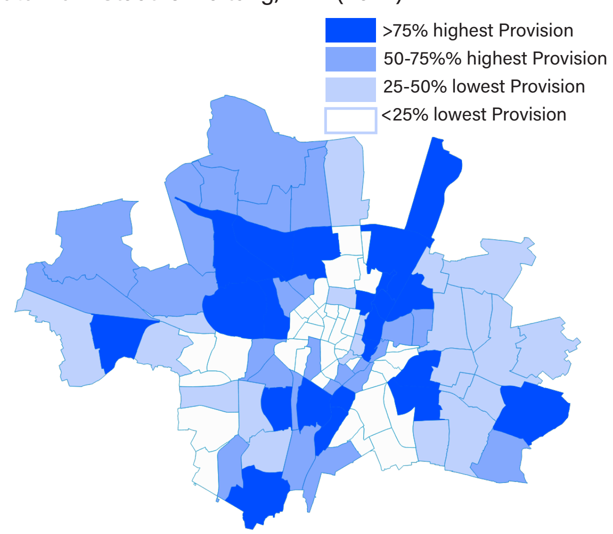

Figure 44: Carbon GI Interventions. Based on data from Stadtverwaltung, L.m. (2024)

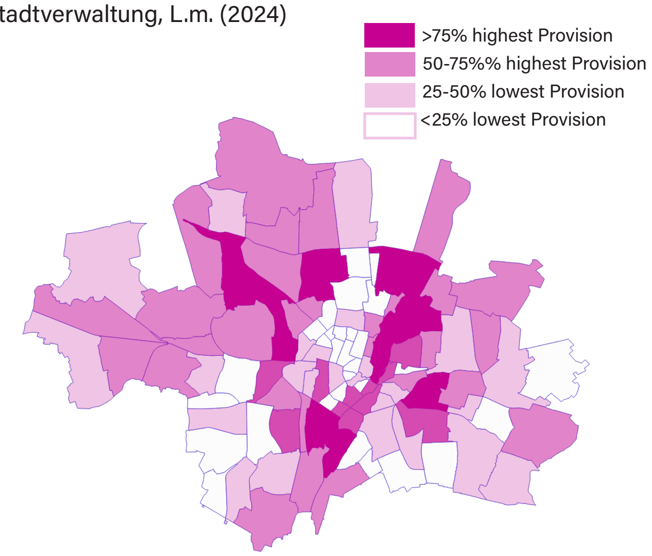

Figure 42: Air Quality GI Interventions. Based on data from Stadtverwaltung, L.m. (2024)

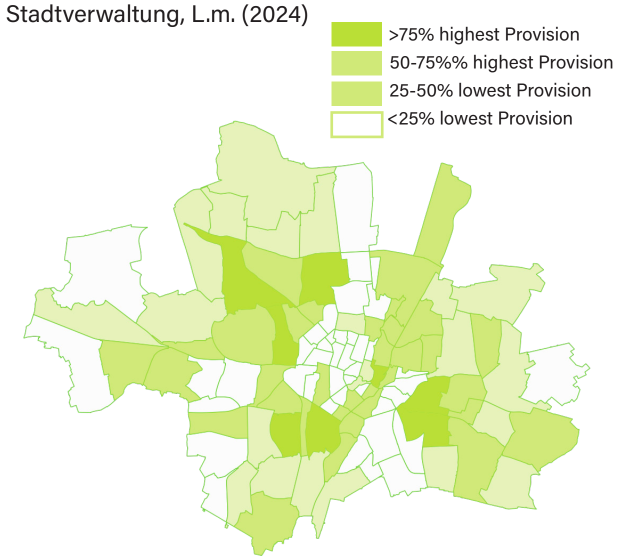

Figure 45: Accessability GI Interventions. Based on data from Stadtverwaltung, L.m. (2024)

3.4 Identification of Spatial (Mis)matches

QGIS Workflow for Interventions Count

Compared to a manual count of interventions for each neighborhood, the automation of this process offers a faster and less error-prone workflow, which is enabled by the digitalization of the STEP2040 as single layers in the Geoportal of the city of Munich. Using R Studio and QGIS Raster and Vector processing tools as shown in figure 46, one map for each justice dimension displaying the impact of the STEP2040 interventions on each dimension computed.
This mapping is then set in comparison with the mapping from chapter 3.1, making explicit the spatial (mis)matching of justice challenges and STEP2040 interventions.

Derivation of Spatial (Mis)match Maps

The spatial (mis)matching maps derived from this methodology are presented in the following for each justice dimension. The worst-matched neighborhoods are among the 25% with the most environmental challenges, hence with the highest demand, as well as under the 25% quantile of intervention impact, hence the neighborhoods with the lowest provision of GI interventions. Other mismatches, such as high to medium demand (25-50% Quantile) and low Provision (25%) or vice versa are also indicated in the maps. The spatial (mis)match mapping was then overlayed with the three socio-demographic indicators. As outlined in chapter two, this follows the capability approach which emphasizes individual differences in the capability to adapt. The elderly, children and low-income households were therefore considered as particularly vulnerable demographic groups. As a result, the (mis)alignment of demand and provision reveal neighborhoods that are socio-environmentally challenged and potentially overlooked in the strategic development plan.

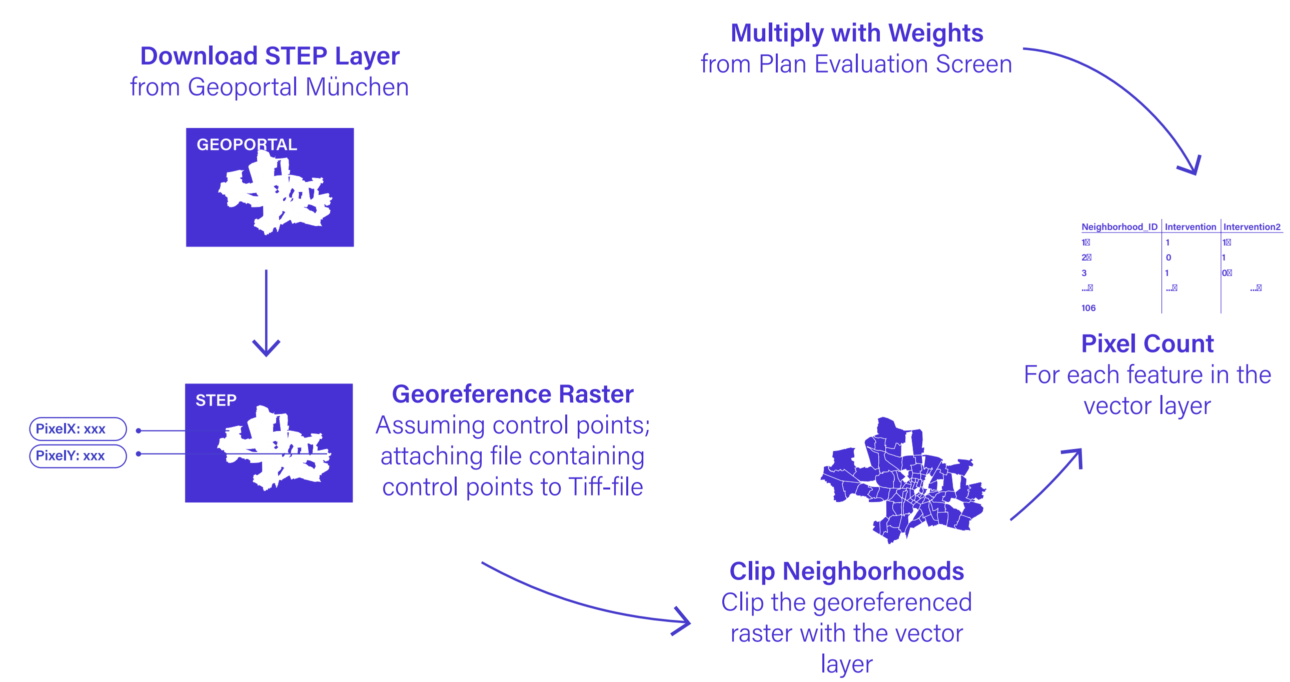

Figure 46: Workflow for Spatial (Mis)matching of the Justnature Justice Mapping and STep2040 Interventions.

04 Results: Spatial (Mis)match Mapping

Heat Stress Zones

The overlay of where urban heat stress is highest and where mitigation interventions are allocated shows that eight neighborhoods are mismatched in terms of thermal demand and interventions provision. Out of these, five neighborhoods face socio-demographic challenges in form of a high amount of families with children and low income households and are therefore in risk of becoming socio-ecological justice blind spots. The intervention allocation map suggests that the mismatched neighborhoods for the thermal justice dimension are driven by the intervention Park Miles.

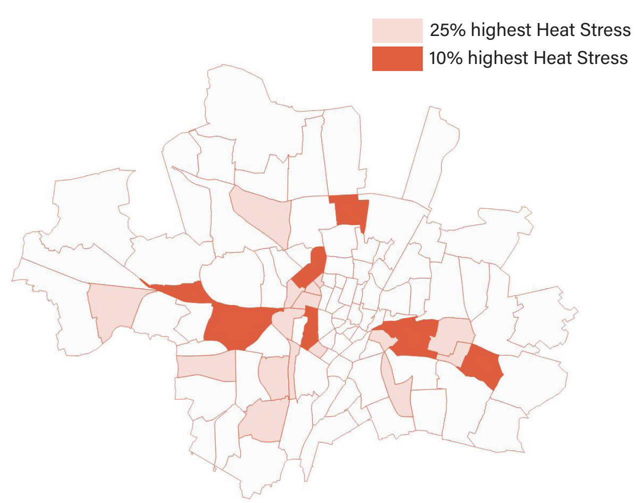

Figure 47: Thermal Demand - Heat Stress. Data from Gantioler et al. (2023)

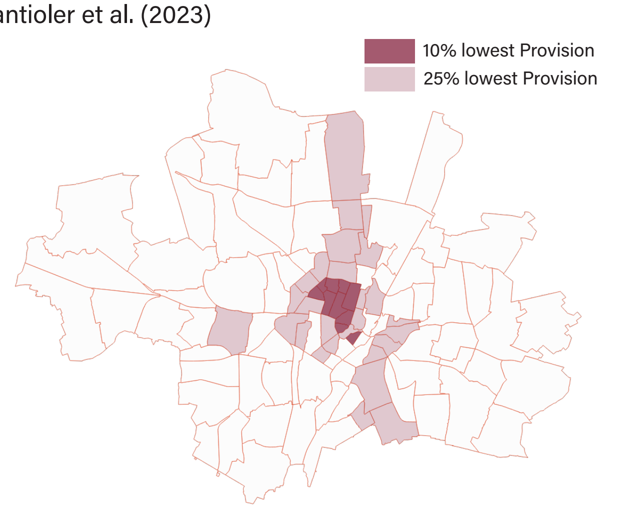

Figure 48: Thermal Intervention Allocation. Based on data from Stadtverwaltung, L.m. (2024)

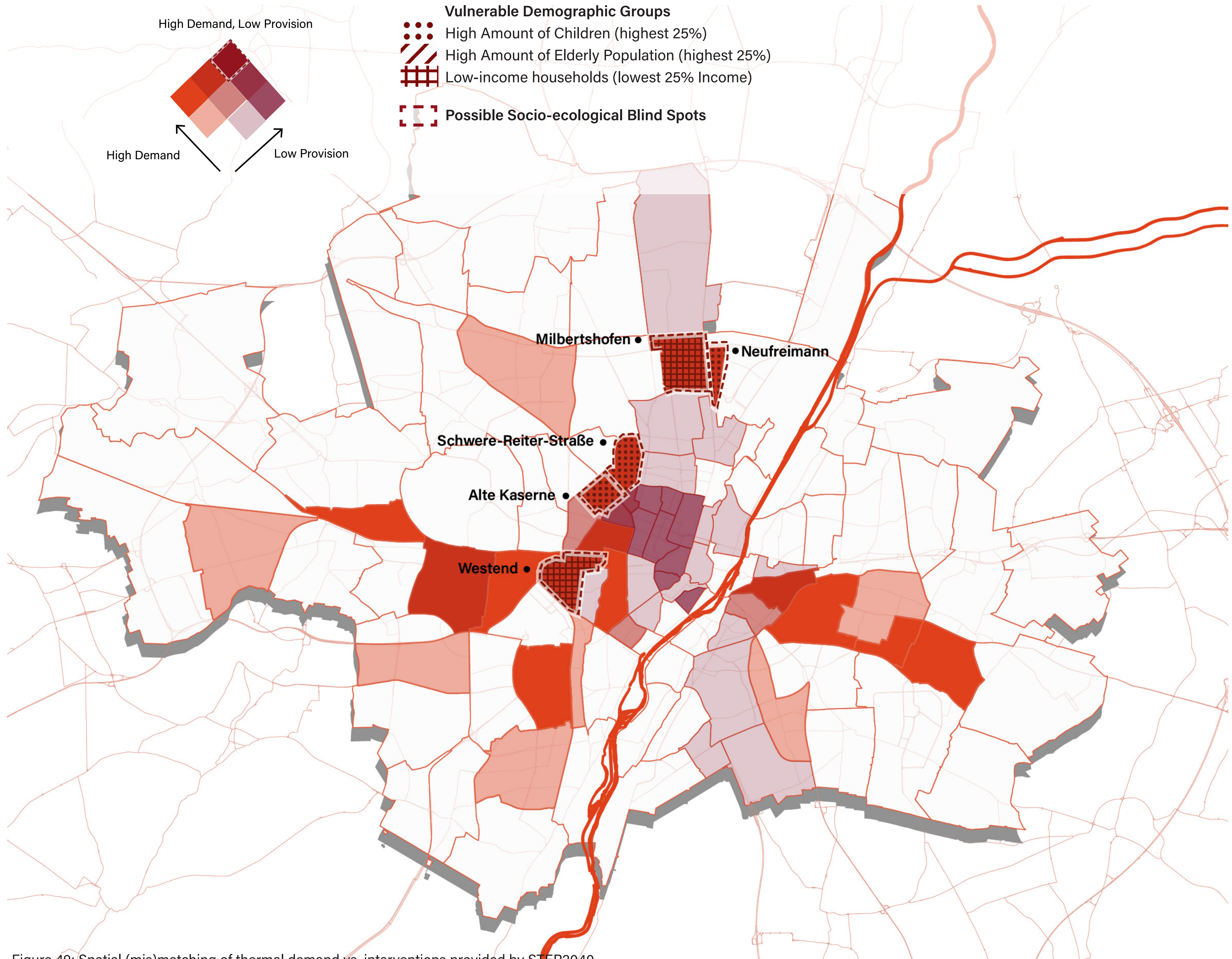

Figure 49: Spatial (mis)matching of thermal demand vs. interventions provided by STEP2040

Air Quality Risk Areas

The demand and provision side of air quality risk areas both show a rather dispersed spatial patterns, while problematic neighborhoods are rather concentrated in the central to medium central city parts. Out of the four strong mismatches, two exhibit socio-demographic challenges. Further, out of four neighborhoods with a low provision and medium high demand have additional socio-demographic vulnerability.

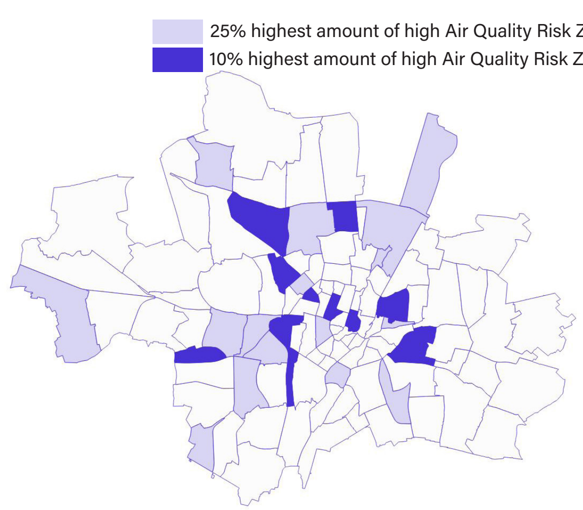

Figure 50: Air Quality Demand - Air Quality Risk Zones. Data from Gantioler et al. (2023)

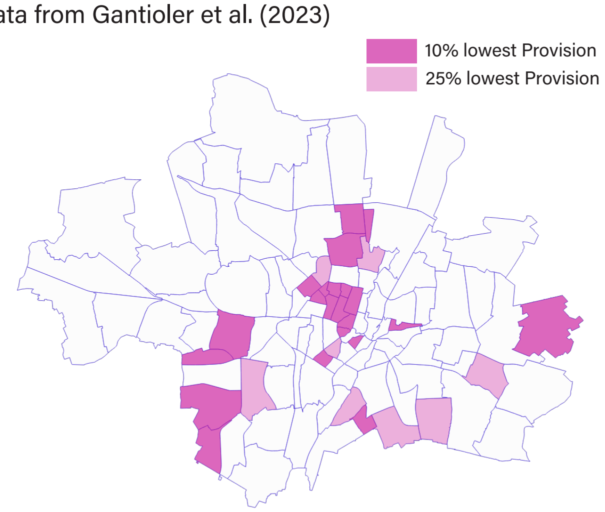

Figure 51: Air Quality Intervention Provision. Based on data from Stadtverwaltung, L.m. (2024)

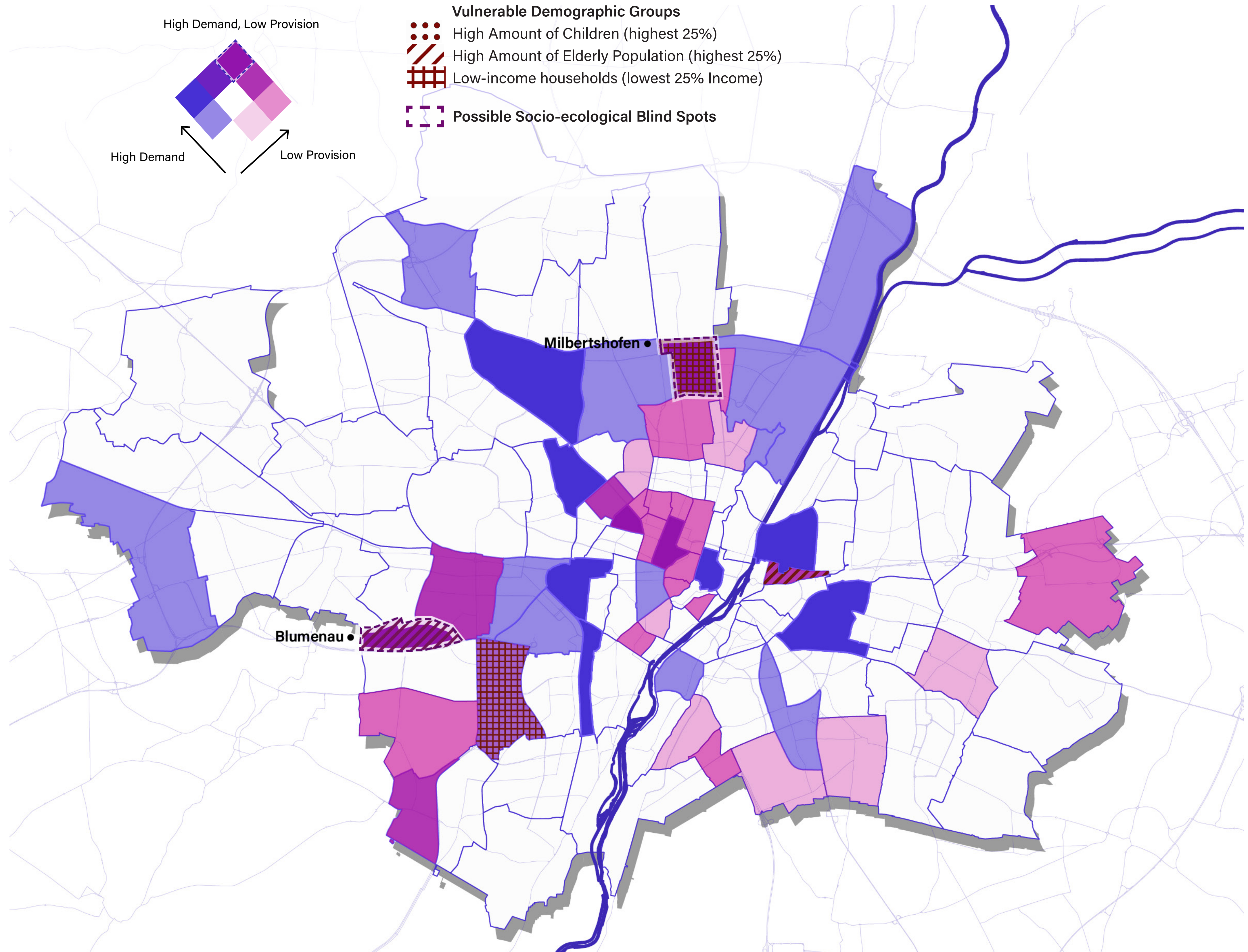

Figure 52: Spatial (mis)matching of air quality demand vs. interventions provided by STEP2040

PM2.5 Concentration

Spatial mismatches for the PM2.5 concentration are mainly evident for the city center to norther parts of the city. Out of the four strong mismatches, two neighborhoods are also socio-demographically challenged. Eight neighborhoods, mostly in the city center, have a low provision of interventions and experience medium to high PM2.5 concentrations. Considering that the PM2.5 distribution is strongly left-skewed, indicating that a minority experience substantially elevated pollution exposure, the potential risk of the neighborhoods with the highest demand, marked with the outline in the map, is reinforced, while the risk of the eight neighborhoods with the medium to high demand might not be as severe.

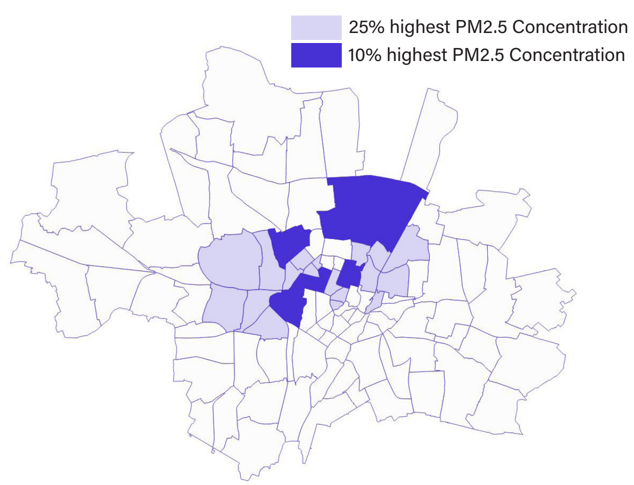

Figure 53: Air Quality Demand - PM2.5 Concentration. Data from Gantioler et al. (2023)

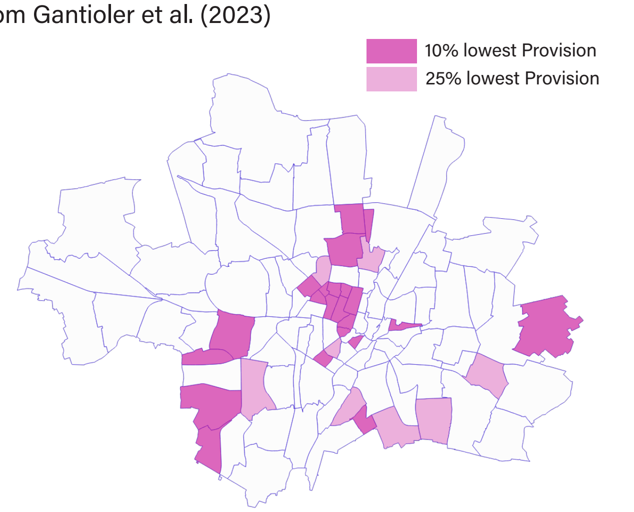

Figure 54: Air Quality Intervention Provision. Based on data from Stadtverwaltung, L.m. (2024)

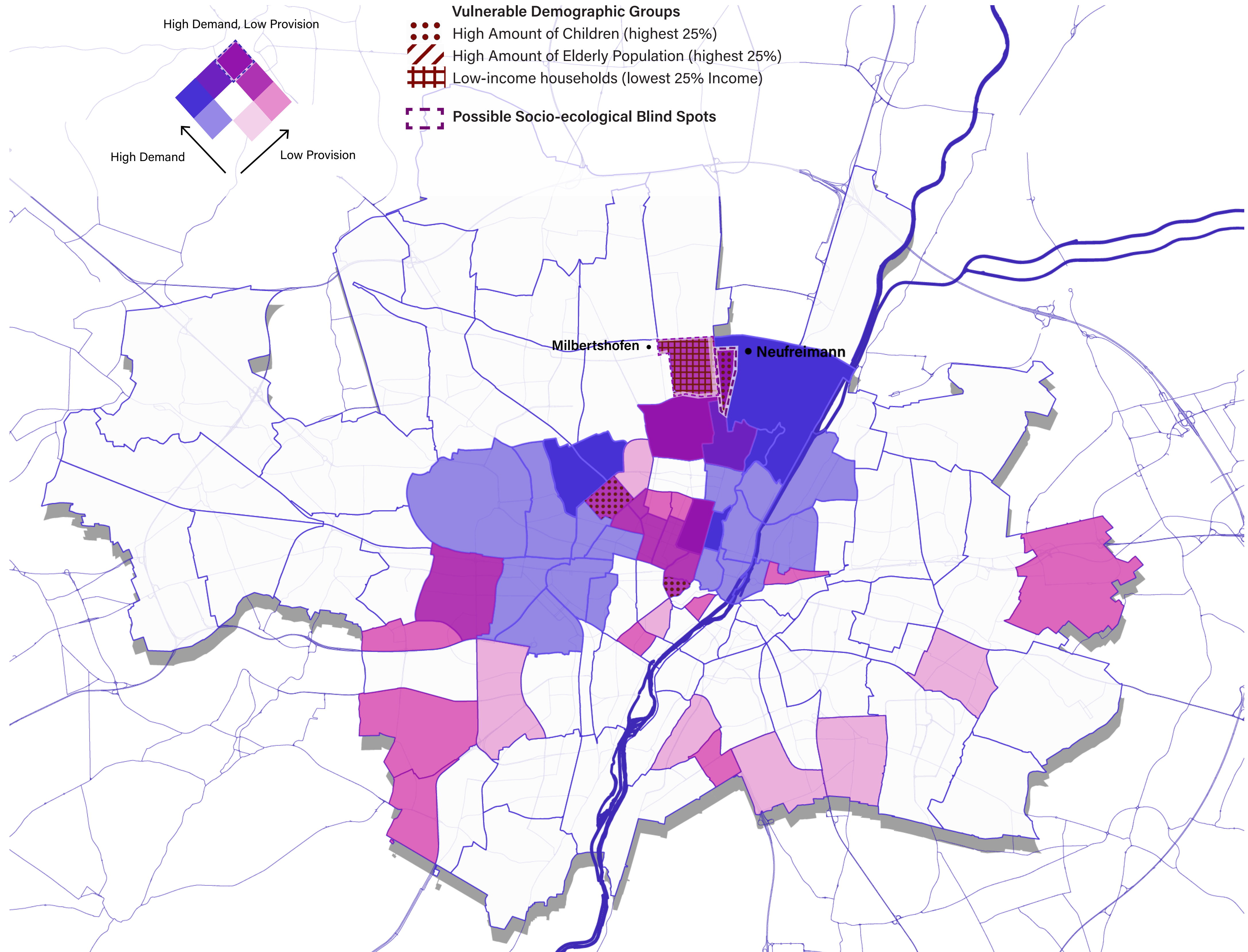

Figure 55: Spatial (mis)matching of air quality demand as PM2.5 concentration vs. interventions provided by STEP2040

Green Space Connectivity

The green space connectivity mismatching highlights the strong performance of the perihpheral areas and the concentration of challenges in the city center. Due to the lack of meaningful socio-demographic indicators that represent non-human stakeholder perspectives, no neighborhoods are marked as blind spots, despite the identification of ten strongly mismatched neighborhoods.

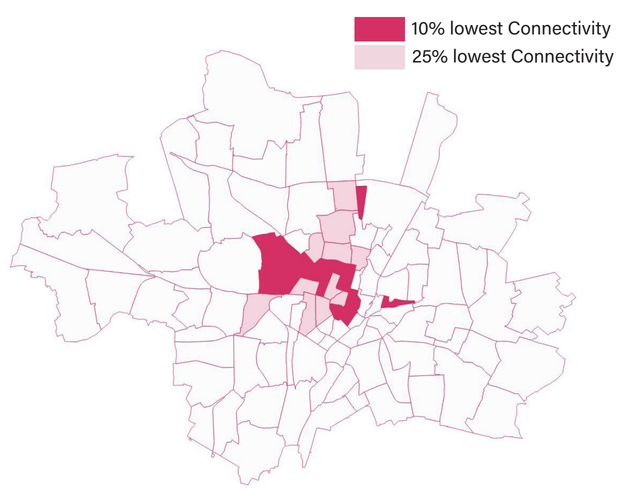

Figure 56: FFH Demand - Green Space connectivity. Data from Gantioler et al. (2023)

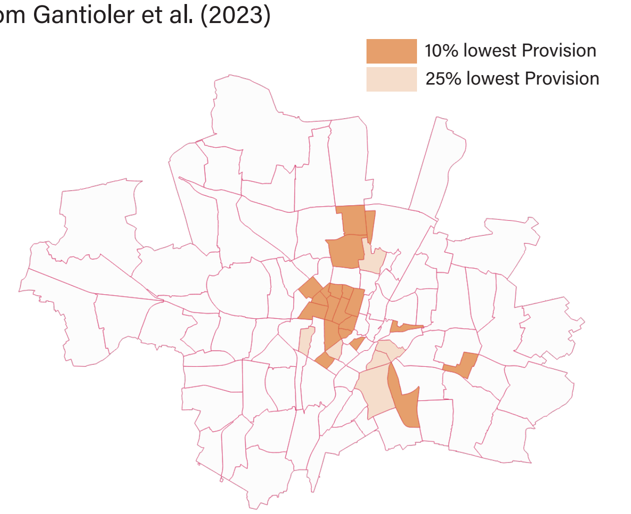

Figure 57: FFH Interventions Provision. Based on data from Stadtverwaltung, L.m. (2024)

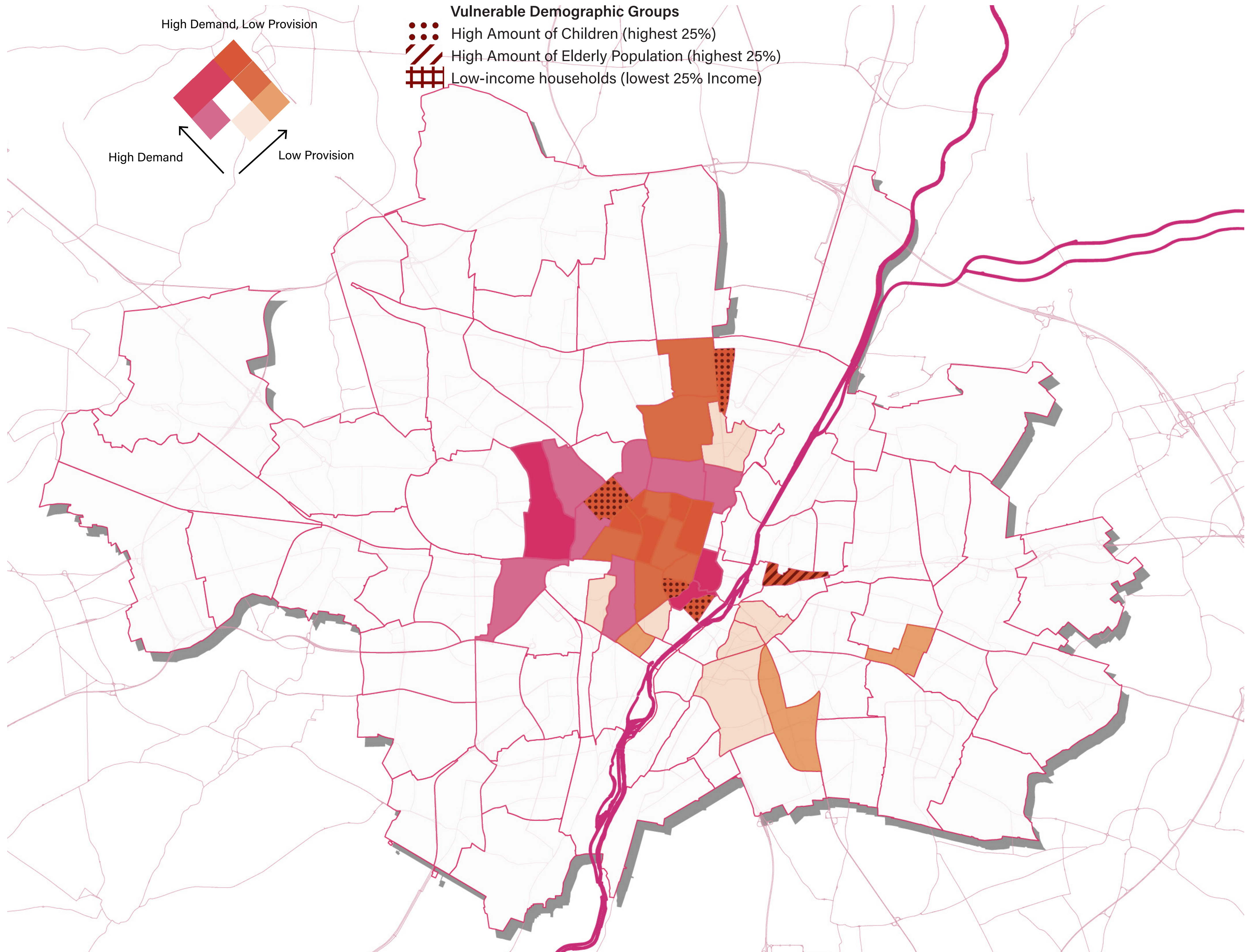

Figure 58: Spatial (mis)matching of FFH demand as green space connectivity vs. interventions provided by STEP2040

Vegetation Quality

Analogous to the green space connectivity indicator, no blind spots are marked due to the unsuitability of socio-demographic indicators. However, the strong need for targeted interventions to improve the vegetation quality is visible for the inner city.

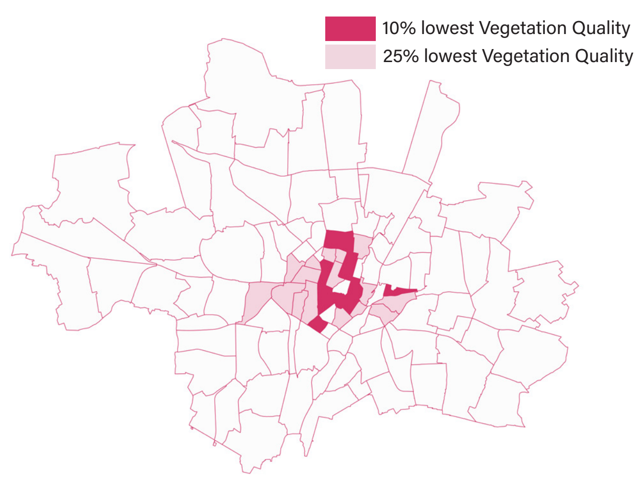

Figure 59: FFH Demand - Vegetation Quality. Data from Gantioler et al. (2023)

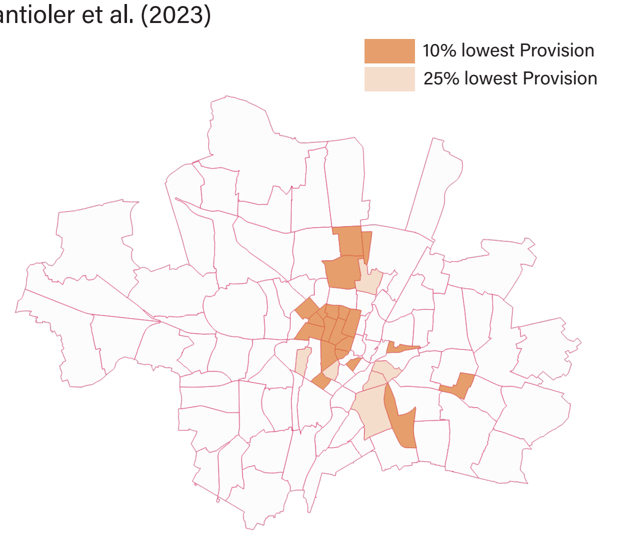

Figure 60: FFH Interventions Provision. Based on data from Stadtverwaltung, L.m. (2024)

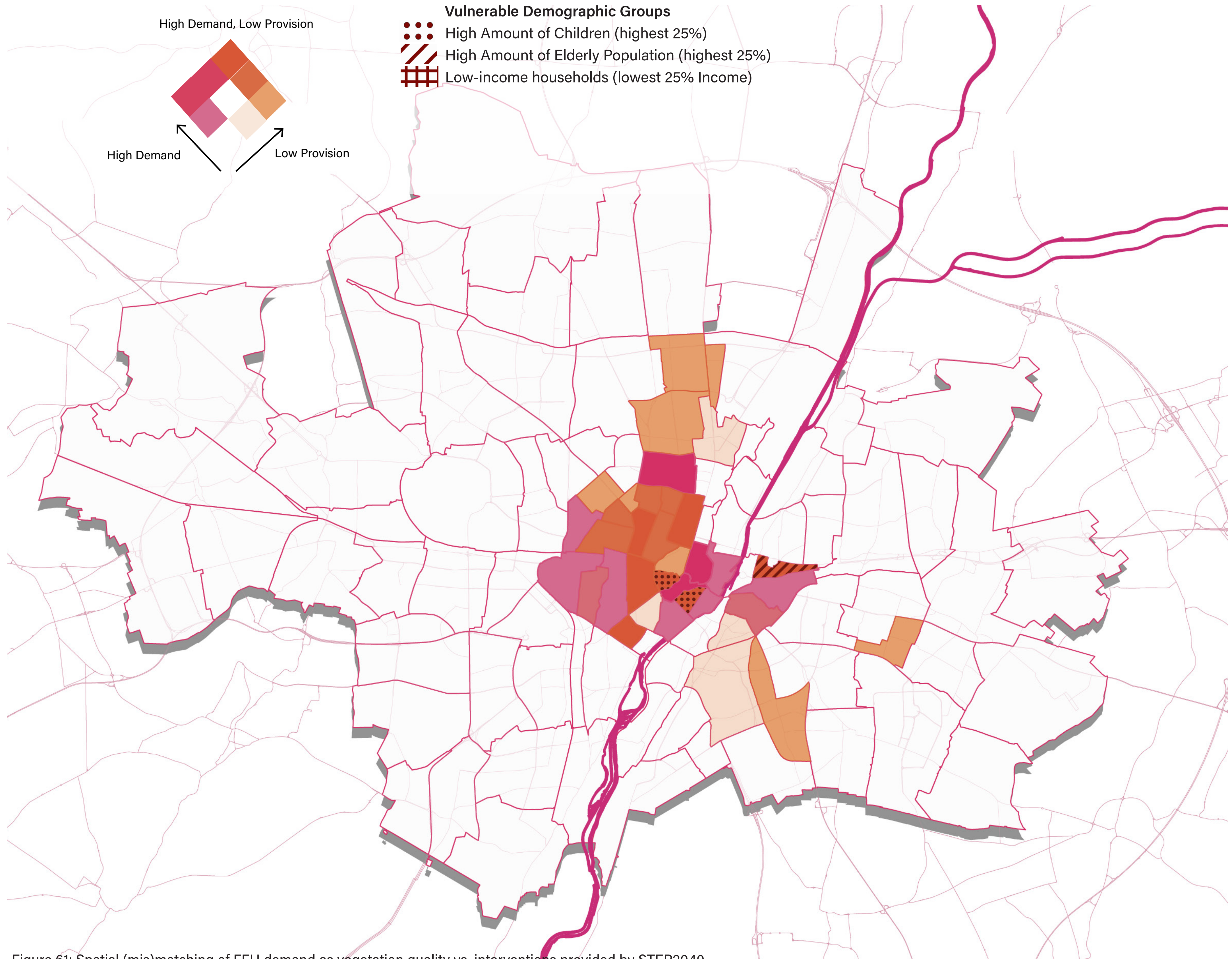

Figure 61: Spatial (mis)matching of FFH demand as vegetation quality vs. interventions provided by STEP2040

Carbon Emission

The mismatchings shows that interventions do not focus sufficiently in the most problematic areas of the inner city. There are however, no strong mismatches, as there is still a low to medium allocation of interventions in the inner city. Two of these not well matched neighborhoods have a high amount of families with children and elderlies and are therfore considered as potentially

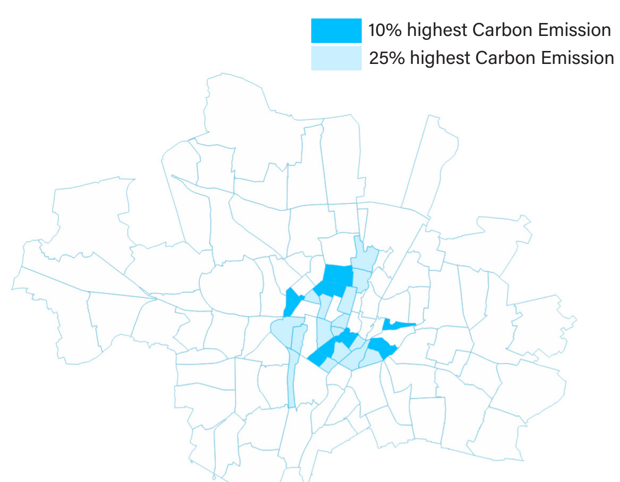

Figure 62: Carbon Demand - Carbon Emission. Data from Gantioler et al. (2023)

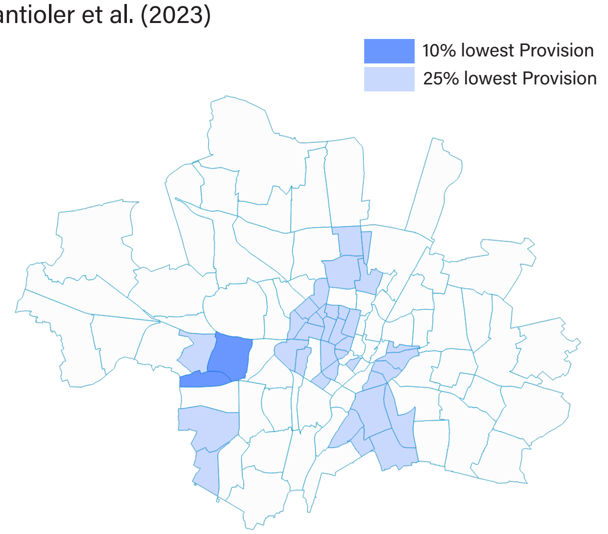

Figure 63: Carbon Intervention Provision. Based on data from Stadtverwaltung, L.m. (2024)

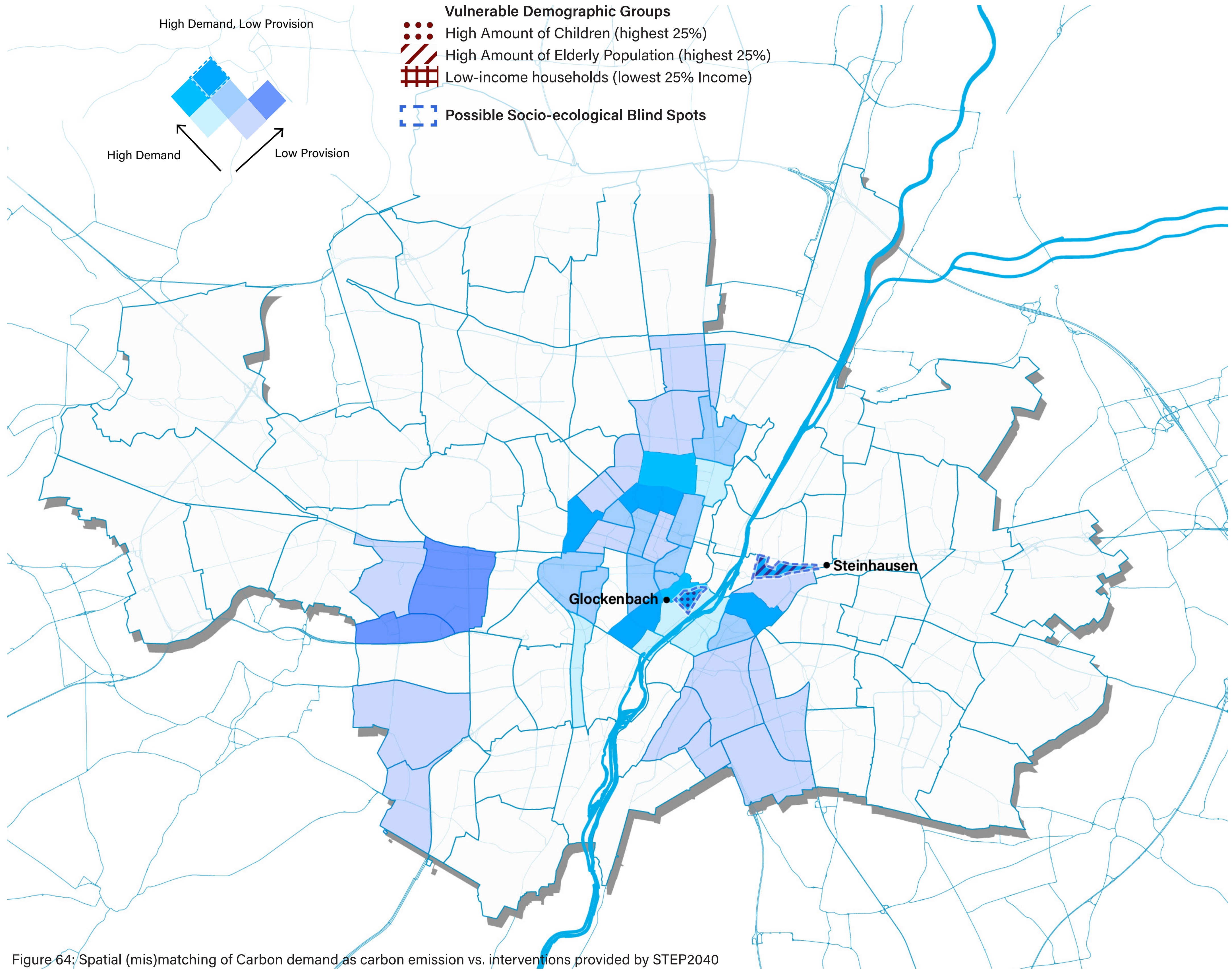

Figure 64: Spatial (mis)matching of Carbon demand as carbon emission vs. interventions provided by STEP2040

Carbon Absorption

Similar to the carbon emission, no severe mismatches are evident. Two neighborhoods in the inner city with a high amount of children might still bear a socio-ecological justice risk, demanding a higher provision of interventions.

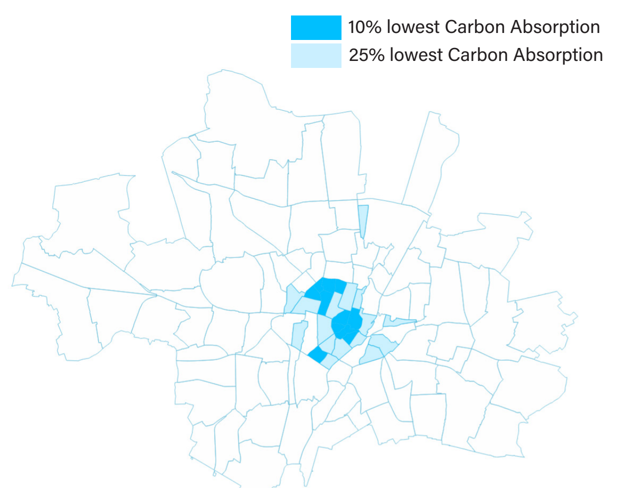

Figure 67: Carbon Demand - Carbon Absorption. Data from Gantioler et al. (2023)

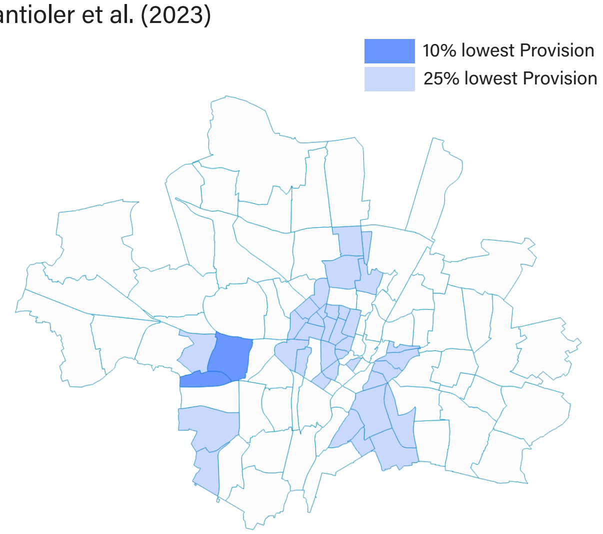

Figure 68: Carbon Intervention Provision. Based on data from Stadtverwaltung, L.m. (2024)

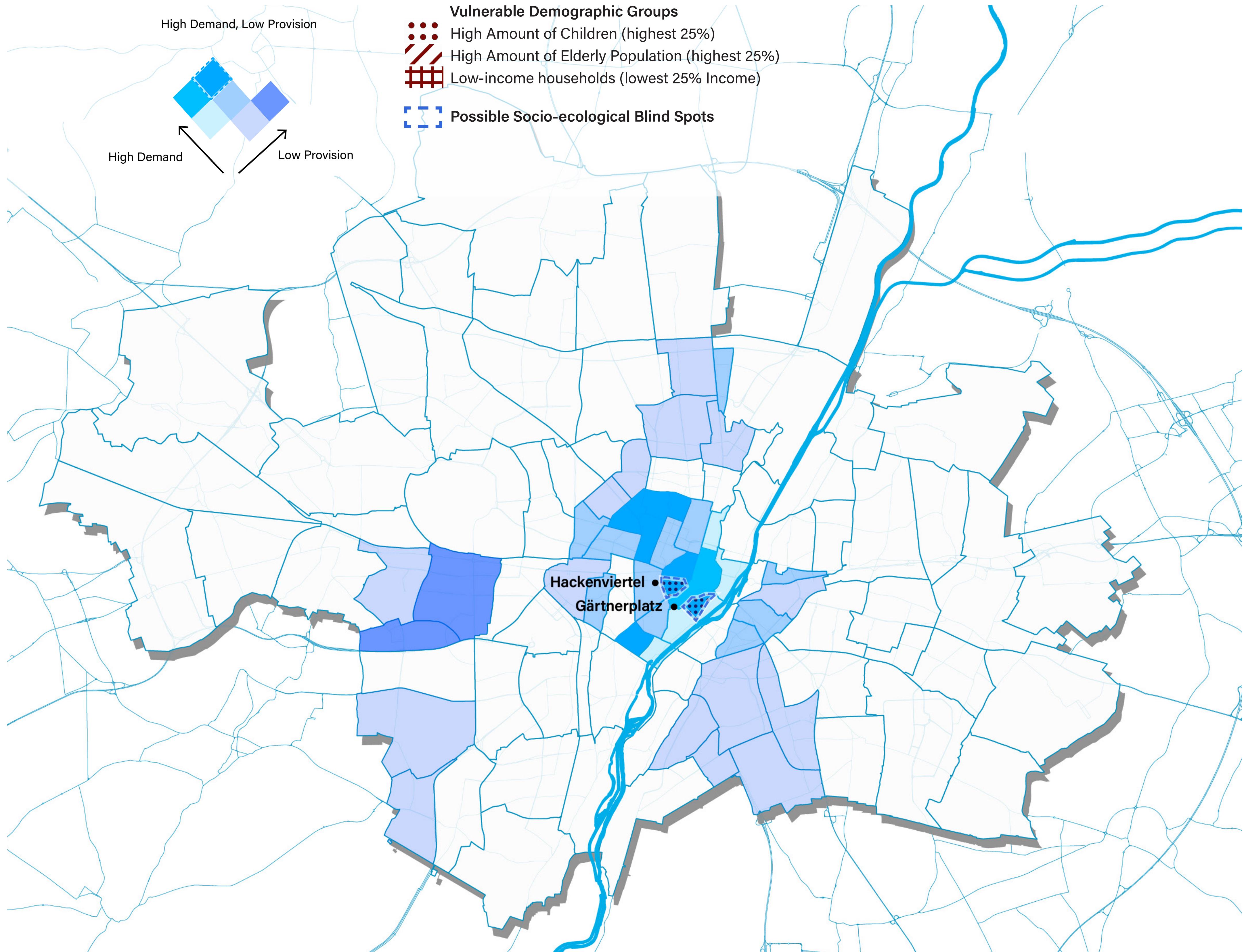

Figure 70: Spatial (mis)matching of Carbon demand as carbon absorption vs. interventions provided by STEP2040

Green Space Accessability

The walkable access to green space is lowest in peripheral districts, while green infrastructure interventions are concentrated in areas already well served, especially inner-city areas. The overlay reveals four peripheral neighborhoods where high vulnerability coincides with poor green space access and limited intervention, out of which three are socio-demographically challenged. It is important to note, however, that none of the neighborhoods are strongly mismatched.

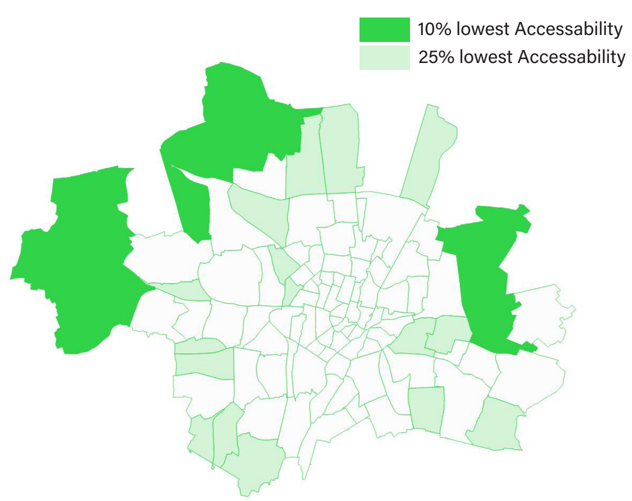

Figure 71: Accessability Demand. Data from Gantioler et al. (2023)

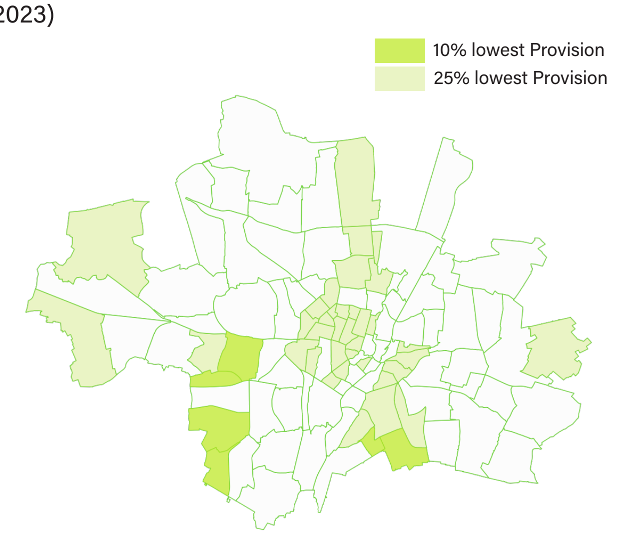

Figure 72: Accessability Intervention Provision. Based on data from Stadtverwaltung, L.m. (2024)

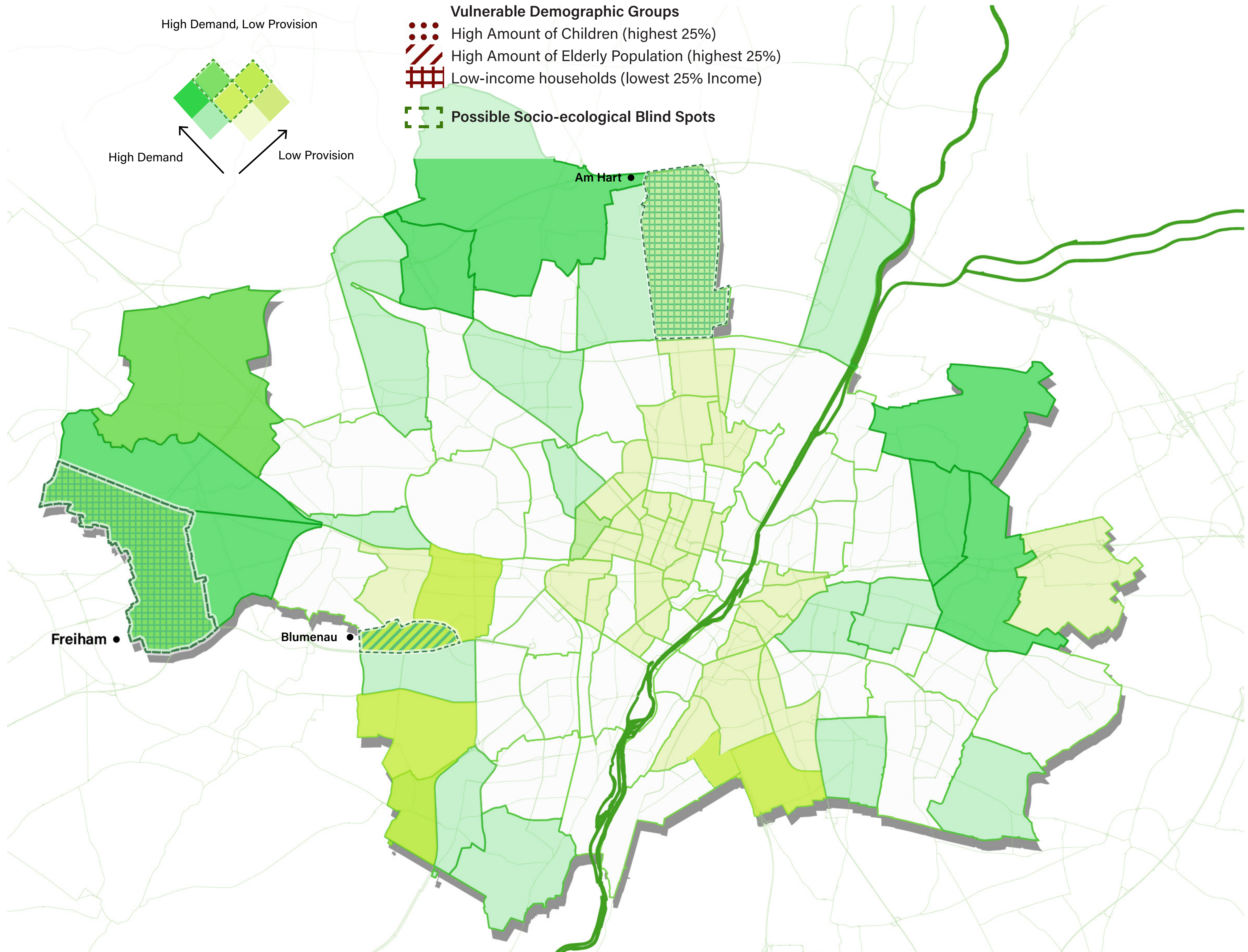

Figure 73: Spatial (mis)matching of Accessability demand vs. interventions provided by STEP2040

Patterns of Spatial (Mis)Matching

The twelve neighborhoods identified as potential blind spots are displayed in figure 74 as synthesis maps of the previous mappings. The most mismatched justice dimensions are the thermal and air quality dimension.
The geopgraphical patterns emerged across the five justice dimensions are outlined in the following.

Peripheral Underserved Areas

A pattern evident in the thermal justice, air quality justice and particularly green space accessibility is that the outer, peripheral neighborhoods often experience higher environmental burdens receive fewer interventions, while containing socio-demographically vulnerable populations (e.g. low income, elderly, children). This is particularly evident in the norther part of the city, i.e. Milbertshofen and Am Hart. It is important to note, however, that the results for the green space accessability indicator might include some distortion as they did not consider Munich's green belt as green space.

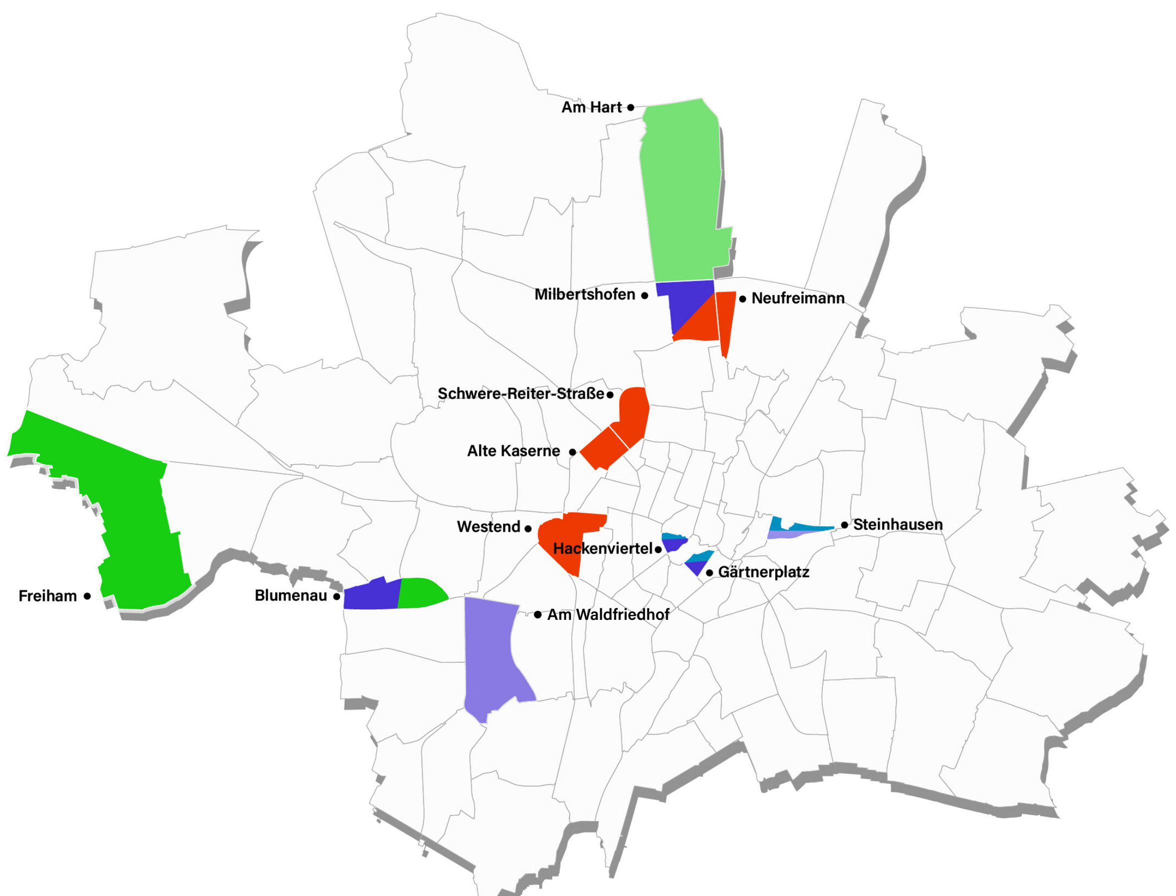

Figure 74: Overview of spatial (mis)matching results with the neighborhoods identified as socio-ecological critical and potentially overlooked.

East-West Asymmetry

Another notable pattern is the difference between neighborhoods east and west of the river Isar. With the exception of one neighborhood, all neighborhoods identified as mismatches are located in the western part of Munich. Except for the spatial justice and thermal justice intervention, this pattern is quite clearly driven by lower ecological demands on the eastern side.

Inner-City Priority Bias

Altough the inner city appears to be a highly critical areas due to a multitude of environmental burdens, there were no strongly mismatched neighborhoods detected. Moreover, as the inner city has less vulnerable groups, only two inner city neighborhoods were found to be potentially overlooked, while the neigborhoods in between the inner city and the peripheral areas appear more critical based on the spatial mismatching results. Strong mismatches in the inner city were only evident for the Flora-Fauna-Habitat dimension.

Clustering of Interventions

Some of the patterns appear to stem from the spatial clustering of interventions along the Park Miles, specifically the Isar.

05 Discussion

5.1 Contextualisation of Findings

Contextualisation of findings

12 neighborhoods have been identified as potentially overlooked areas that may bear social-ecological justice issues. To assess the relevance and validity of these results, the neighborhoods are contextualized by comparing them to existing justice mappings for the city of Munich. Specifically, three mappings are considered: the Stadtteilstudie conducted by the Municipality of Munich, the Mobilitäts(un)gerechtigkeitsatlas developed by the Technical University of Munich (TUM), and the Urban Environment and Social Inclusion Index (UESI) developed by the University of North Carolina. While the Stadtteilstudie focuses exclusively on socio-demographic indicators, the latter two adopt a composite mapping approach, similar to the methodology applied in this study.

The social service department of Munich monitors various socio-demographic indicators across the city's districts and derives an annual composite score to classify neighborhoods as "socially challenged". Based on the most recent mapping from 2023, nine out of the 12 neighborhoods identified in this study exhibit medium to very high levels of social challenges. The remaining three neighborhoods were selected due to their high proportions of elderly residents, aligning with findings from the Stadtteilstudie. However, two neighborhoods — Echarding and Balanstraße-West — were marked as highly socially challenged in the Stadtteilstudie and as ecologically challenged in the spatial (mis)matching analysis, yet they were not marked as critical neighborhoods in the spatial (mis)matching. Looking more closely at the composition of the social challenges score, this discrepancy can be explained by a combination of high unemployment rates and share of immigrants, both socio-demographic variables that were not taken into account in this work.

The Mobilitäts(un)gerechtigkeitsatlas produced by the Chair of Settlement Structure and Transport Planning at TUM evaluates the distribution of mobility access across Munich's neighborhoods. This atlas combines a composite score for socially disadvantaged groups (similar in structure to the Stadtteilstudie) with a traffic disadvantages score. The traffic disadvantages score is composed of four indicators: availability of public transport, modes of movement, walkability to public institutions, and traffic risks, such as accident rates. Notably, the mapping of traffic disadvantages shows a high degree of congruence with the green space accessibility mapping conducted in this study, particularly at the city's peripheries, where neighborhoods perform poorly. All neighborhoods identified as problematic in terms of spatial justice in this work also appear in the mobility (in)justice mapping. Seven out of eleven neighborhoods characterized by high traffic injustice in the Mobilitäts(un)gerechtigkeitsatlas were found to have sufficient green infrastructure provision in the STEP2040, suggesting that accessibility injustices are widely acknowledged within Munich's urban development strategies.

The Urban Environment and Social Inclusion Index (UESI) measures how environmental burdens and benefits are distributed across neighborhoods differing in income and population characteristics. The UESI estimates distributional equity by calculating an Environmental Concentration Index — a composite measure of sustainable transit access, tree cover (benefits), and exposure to nitrogen dioxide, particulate matter, and urban heat island intensity (burdens). This Environmental Concentration Index is analyzed alongside the Gini Coefficient, which reflects income distribution disparities. (Hsu et al., 2020) The UESI identified systematic equity differences in Munich for nitrogen dioxide distribution, urban heat island exposure, and proximity to public transportation. These environmental burdens disproportionately affect lower-income neighborhoods, thereby reinforcing patterns of air quality and thermal injustice found in the spatial (mis)matching. However, the UESI findings suggest less evidence for systematic accessibility injustices in Munich, which slightly contrasts with the results of the green space accessibility mapping conducted in this study.

A possible role of socio-ecological justice in urban planning processes of Munich

To further understand the implications of the spatial (mis)matching results for current planning practices, the identified neighborhoods were compared with the priority areas outlined in one of Munich's development planning tools, the Handlungsraumkulisse (iHRK). The iHRK, introduced in 2010, serves as a bridge between strategic planning and implementation by identifying priority zones for targeted action. The areas are reassessed approximately every two years, allowing for a flexible and adaptive planning framework. This adaptable process is embedded in the Münchner Modell der Handlungsräume, which allows for the removal, addition, or modification of action areas based on evolving needs and challenges. The framework's emphasis on integrated action areas, which are developed and implemented in collaboration with various stakeholders and are in alignment with other planning documents such as the STEP2040, aims to enable a holistic approach to addressing complex urban challenges. These challenges are derived based on six dimensions: green and open spaces, housing, work and economy, health, and education. This prioritization process should allow for a flexible and responsive approach to urban planning, enabling the city to address its most pressing challenges while remaining adaptable to future changes.

Thus, the planning tool is highly relevant for the possible inclusion of socio-ecological justice matters.
The spatial comparison of the most critical neighborhoods identified in the spatial (mis)matching with the action areas defined in the action space concept as displayed in graphic XX shows that there is a alignment of the neighborhoods, notably in the north, south and west of Munich. None of the neighborhoods in the east that were marked as action areas were identified as critical in the spatial (mis)matching. This could, however, also speak for the fact that these areas already entered the implementation stage and are therefore already sufficiently provided with GI. A strong alignment is particularly evident for the neighborhoods Fürstenried-West and Milbertshofen-Am Hart, both identified as critical in this work and also marked as top-priority action areas.

However, a closer look at the reasons for the prioritization reveals some differences: While the document acknowledges disparities in environmental benefits and burdens across Munich's action areas, it does not detail a specific assessment methodology. Instead, focus is laid primarily on socio-economic factors and how they intersect with urban development such as the housing situation. However, the document also indirectly addresses environmental disparities by highlighting specific challenges and goals related to environmental quality, as i.e. the need to improve the bioclimate in highly dense inner-city areas and reduction of traffic-related noise pollution. Similarly, the importance of preserving and enhancing green spaces in certain action areas is discussed, suggesting a recognition of the need to improve access to environmental services. In Moosach, for example, unfavorable bioclimate conditions during summer are specifically mentioned.

These differences may stem from divergent understandings of justice in urban planning, which often overlook the interaction between socio-demographic and ecological factors. However, due to its suitability for mitigating complex interests and conflicts by linking more formalized planning and non-municipal stakeholders, the Münchner Modell der Handlungsräume seems to be a promising tool for the integration of socio-environmental justice concerns and could be an anchoring point for the JUSTNature Mapping approach.

5.2 Review of Methodology

Indicator selection

A core methodological consideration is whether to utilise a standardised set of indicators or to adopt a more context-specific, individually tailored approach. While standardisation enhances comparability across different urban contexts, it risks oversimplification, particularly in socio-demographically diverse settings. For environmental indicators, the literature provides a high level of consensus on key variables such as air quality, green space accessibility and urban heat exposure. The JUSTNature project's set of environmental indicators reflects this consensus and is comprehensive enough to capture a wide range of environmental benefits and burdens across urban areas.

In contrast, selecting socio-demographic indicators was more challenging. These indicators inherently exhibit greater spatial and contextual variability, and their effectiveness depends heavily on local socio-economic dynamics. For example, income levels remain a useful proxy for vulnerability and stratification, as became evident by comparative insights from the Stadtteilstudie. However, relying on generalised socio-economic categories can obscure more nuanced forms of vulnerability. In the case of Munich specifically, existing studies (e.g. the Mobilitätsgerechtigkeitsatlas and the work of Gantioler et al.) suggest that vulnerable groups, such as single-person households and impoverished older adults, are frequently underrepresented in large-scale socio-demographic mapping. Including these groups through more refined indicators could significantly enhance the explanatory power and equity sensitivity of urban justice assessments. Furthermore, as Spinrath and Plessing (2023) have highlighted, local perceptions of climate vulnerability can differ greatly among stakeholders. This underlines a critical methodological tension: identifying vulnerable groups inevitably involves subjective judgements that are susceptible to politicisation. Therefore, the process of selecting indicators requiring careful negotiation and moderation.

A distinctive difference of the JUSTNature Mapping in comparison to other mappings is the inclusion of ecological indicators that do not relate to human stakeholders (Flora-Fauna-Habitat Dimension). None of the other mapping included ecological or environmental indicators that affects only non-human stakeholders.

Identification of Mismatches

Another methodological layer involved analyzing potential mismatches in demand and provision of environmental benefits and burdens. A key concern here is the application of weighting schemes, which, while generally stable within reasonable parameter ranges, can still influence the final outcome and introduce subjectivity. In this work, there is a possibility that the Park Miles intervention was overvalued, which could skew conclusions regarding its relative impact. Nevertheless, establishing and using a transparent weighting matrix offers critical methodological benefits, as it makes explicit which urban planning priorities are emphasized and encourages reflective evaluation of the alignment between interventions and targeted urban challenges. This approach can inform more strategic, goal-oriented planning processes by clarifying which dimensions of justice and resilience are being prioritized. A key finding arising from the spatial overlay of environmental and socio-demographic vulnerability maps was the geographical shift in areas of concern. While high-priority areas initially appeared concentrated in the city centre, the socio-ecological mismatching revealed that peripheral districts also exhibited significant combined burdens. This finding highlights the importance of adopting multi-scalar and integrative perspectives when interpreting spatial patterns of urban inequality. While this does not change the fact that the city centre neighbourhoods are high-priority areas due to high population density and several environmental issues, the methodology highlights potential blind spots that would be more difficult to identify without a systematic assessment.

Data quality and spatial resolution

The analysis was conducted at the level of Stadtbezirksteile, which represents an intermediate level of spatial resolution—positioned between the more detailed Stadtbezirksviertel, as used i.e. in the Stadtteilstudie, and the broader Stadtteile, applied for instance in the UESI Mapping. This intermediate scale offers a compromise: it is more concise and accessible to a broader audience than very fine-grained divisions, while still capturing urban patterns with more nuance than smaller scale mappings. Furthermore, the STEP2040 planning framework also intentionally incorporates a degree of spatial vagueness, which suggests that this scale is generally sufficient to compare the two documents, as well as to detect broader tendencies or spatial trends across the city.

Regarding data correctness, it is important to note that the indicators provided by the JUSTNature project and were not independently validated within the scope of this work. Despite some identified shortcomings—such as inconsistencies in the walkability index to urban green spaces—the overall results aligned well with those from other justice mapping efforts. This level of convergence suggests that, while not flawless, the data holds sufficient validity for drawing meaningful conclusions in the context of this assessment

Criteria	Benefits	Pitfalls	Potentials
Indicator Selection	Use of generic indicators that work in broad variey of contexts + Transferability	Vulnerabilites are context specific and the use of standard or general indicators might lead to overlooked areas. Munich-specific relevant indicators such as single-households or families with high amount of children were not assessed and might have altered the results - Most relevant groups identified?	The integration of existing socio-demographic and environmental mappings, such as the *Stadtteilstudie*, would facilitate the selection of meaningful indicators
Data Quality	Use of open-source data such as Copernicus + Transferability + easy access and fast worklow	Data should be verified for each City to account for city-specific characteristics. This became evident in the Spatial Justice Layer, in which the Green Space Accessability Indicator did not consider the Green Belt that surrounds the city of Munich and has a high recreational value. - Verification for each city required	xxxxx
Scale	Use of data with low to medium spatial resolution (1x1km) on the level of *Stadtbezirksteile*. This facilitates the workflow, as most data is available in this spatial resolution. The use of the Stadtbezirksteile offers a widely known an easily readable scale. + Data Availability + Comprehensability	Some loss of data correctness at the neighborhood boarders due to 1x1km raster. In general: the lower the spatial resolution, the higher the impact of averaged values. - Loss of correctness, some spatial vagueness	Using the further distinction of *Stadtbezirksteile* into *Stadtbezirksviertel* could allow for more precise results.
Computational Workflow	Use R Studio and QGIS. + Low Threshold Access to Open Source Access + individual weighting can be easily incorporated	Some loss of data correctness at the neighborhood boarders due to 1x1km raster. In general: the lower the spatial resolution, the higher the impact of averaged values. - error-prone due to use of two softwares	Integration into one Software, such as the *Geoportal.* + makes city planning process accessable for a wide audience

TABLE 06: OVERVIEW OF METHDOLOGICAL REVIEW.

6. Conclusion

Overall, the findings contribute to the growing body of research emphasizing the importance of multi-dimensional assessments of green infrastructure planning in urban environments. By providing a more nuanced perspective on Munich's strategic development plan, this study has identified areas that may be at risk of unjust future development in terms of social-ecological justice. To further validate these findings, future research should focus on the temporal dynamics of socio-environmental vulnerability, e.g. by looking at past changes in land sealing over a longer period to better identify disparities in green infrastructure demand and provision over time. This, together with a technical validation of the JUSTNature mapping that was not undertaken in this study, could help to increase the exploitation potential of the mapping through the incorporation into other urban planning tools, such as the Münchner Model der Handlungsräume. The methodology provided by the JUSTNature project could be a valuable contribution to a more strategic selection of priority action areas. The work also explored how differences in ecological vulnerability can be assessed by relating them to socio-demographic indicators. While income appears to be the most straightforward indicator, other socio-demographic characteristics are needed to provide a more complete picture of the complex, multifaceted realities of climate change effects on individuals. This applies specifically for the consideration of non-human stakeholders. Despite the growing efforts to take on a multispecies perspective on ecological justice, there is a lack of concrete measurements in form of i.e. indicators. One possibility that future research could explore is the inclusion of Plant Functional Groups such as proposed by Calbi et al. (2024), that provide access to and facilitate the understanding of different needs of plants-groups. Ultimately, a broader societal question in the context of climate change adaptation was brought to the fore in this work: to what extent can and should urban development follow the 'leave no one behind' principle? How do we define equity in the distribution of environmental goods and services, and is an equitable distribution a just distribution? Given the increasing scarcity of resources and the urgent need for climate adaptation, prioritization in urban planning will become even more critical. Adopting a social-ecological justice perspective could provide valuable guidance in making these complex decisions and in navigating toward urban transitions that are not only efficient but also socially desirable.

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Appendix

Descriptive Statistics

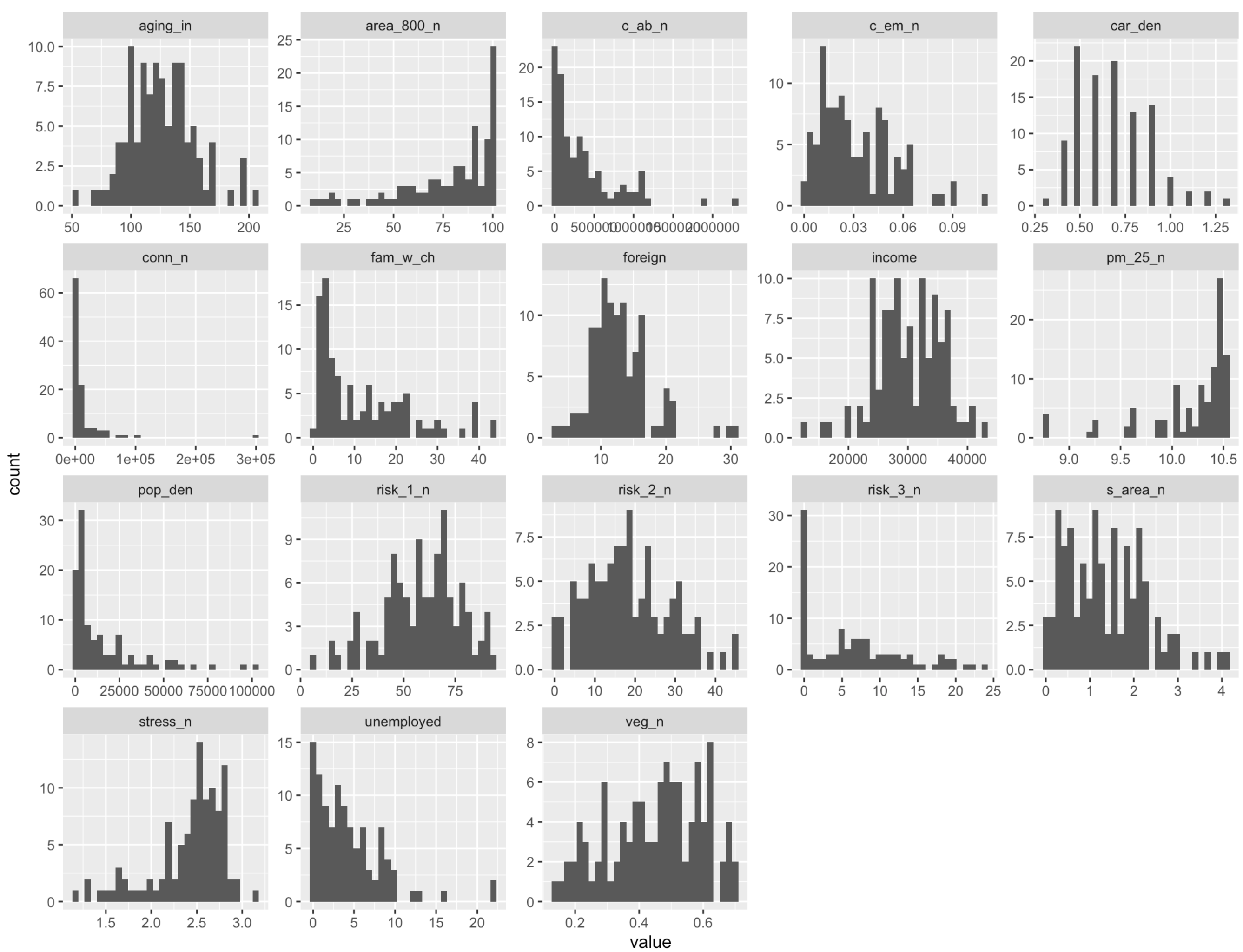

FIGURE 01: HISTOGRAMMS OF INDICATORS

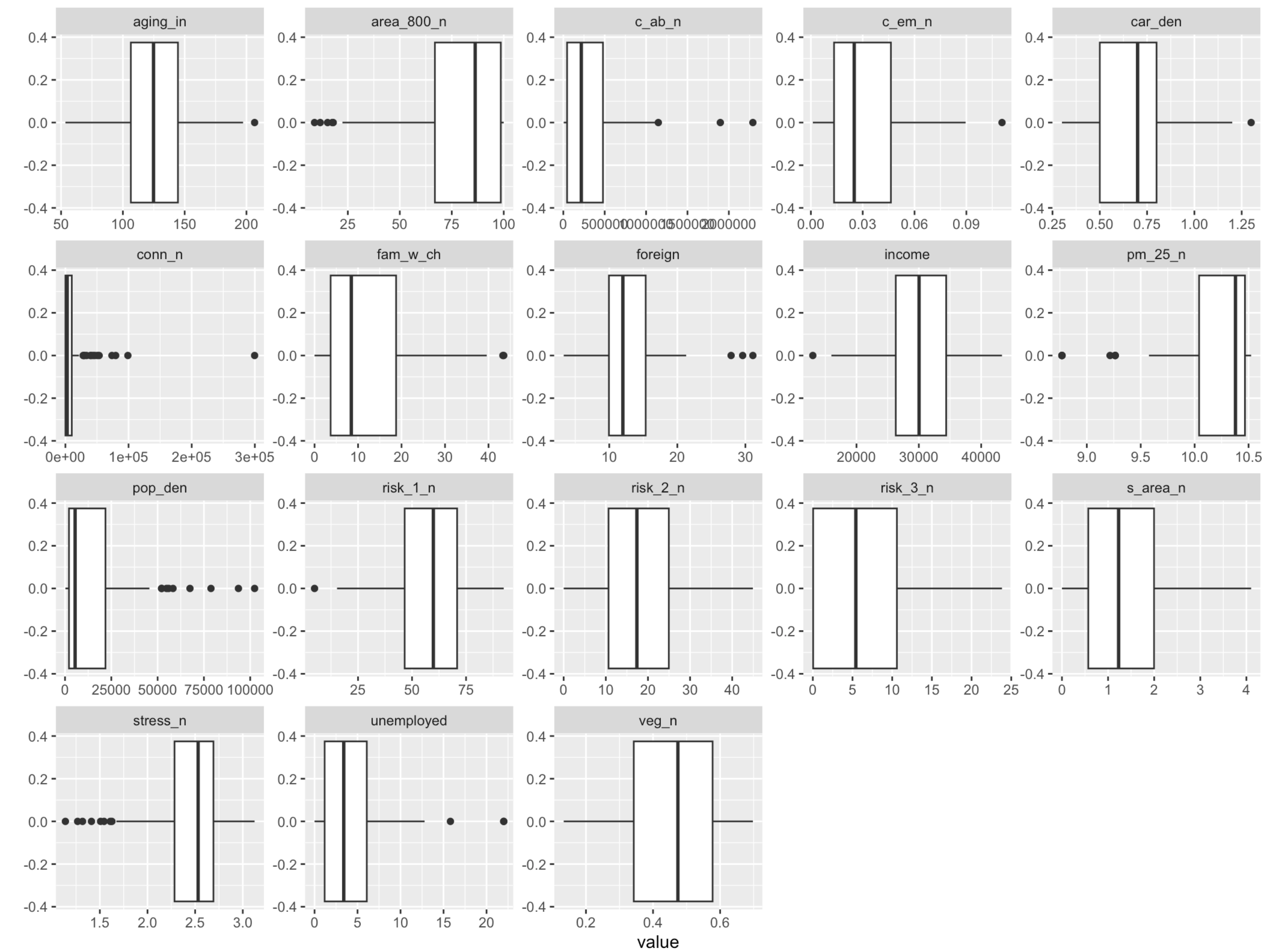

FIGURE 02: BOXPLOTS OF INDICATORS

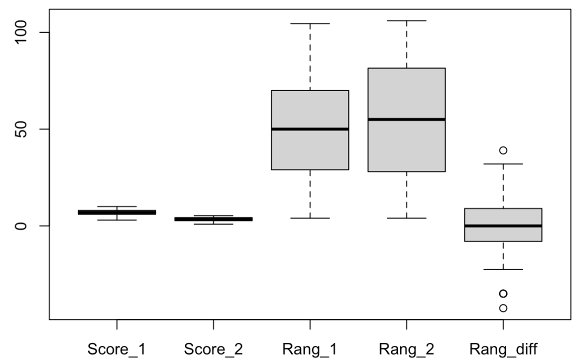

FIGURE 03: SCENARIO ANALYSIS OF AIR QUALITY DIMENSION

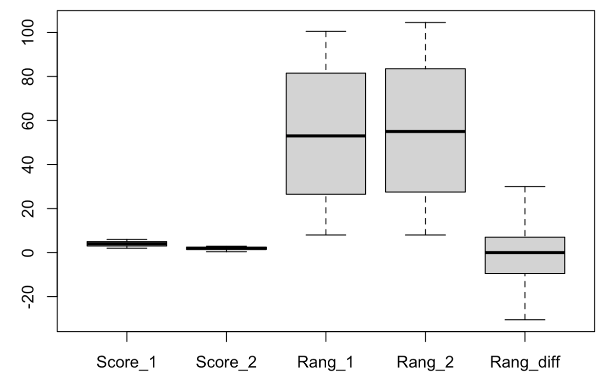

FIGURE 04: SENSITIVITY ANALYSIS OF CARBON DIMENSION

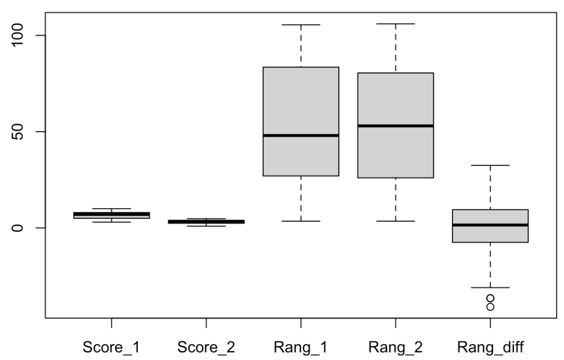

FIGURE 05: SENSITIVITY ANALYSIS OF FFH DIMENSION

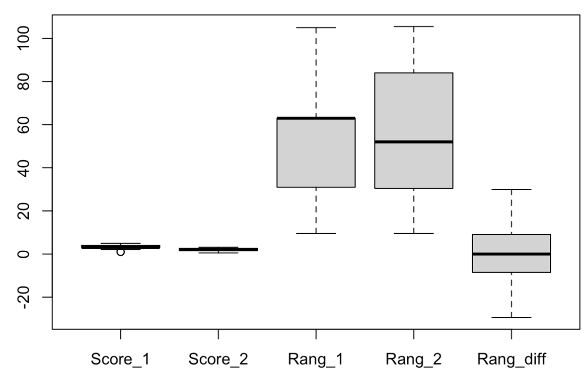

FIGURE 06: SENSITIVITY ANALYSIS OF SPATIAL DIMENSION

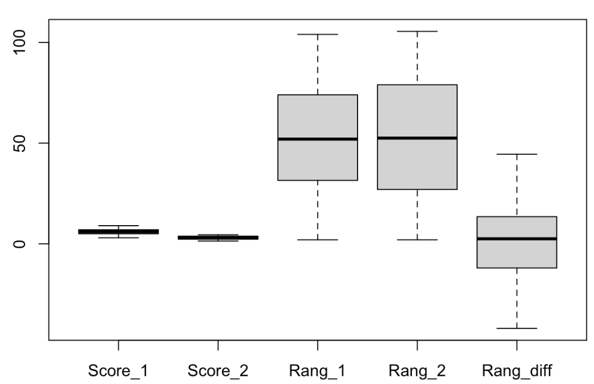

FIGURE 07: SENSITIVITY ANALYSIS OF THERMAL DIMENSION