# Northeast Munich: Forecasting the Land Use and Transportation Impacts of the Proposed Urban Development

Nordost-München:
Prognostizierte Auswirkungen der geplanten Stadtentwicklung auf Landnutzung und Verkehr

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Master's Thesis

# Northeast Munich: Forecasting the Land Use and Transportation Impacts of the Proposed Urban Development

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# MASTER'S THESIS

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### Thesis description:

With the future population of Munich to reach 1.8 million by 2030, urban development to accommodate for the anticipated population demand is vital. As part of the solution, the Department of Urban Planning and Building Regulation from the City of Munich are currently investigating concepts for developing the 'Northeast' area of Munich. The 600 hectares of land under consideration is situated on the east of the airport line (S-Bahn line S8), at the Bogenhausen / Trudering-Riem area. Development is to take place gradually in the coming decades and the Department of Urban Planning and Building Regulation have proposed three possible scenarios.

This study considers the proposed three scenarios by forecasting the land use and transportation impacts of the proposed urban development. The assessment will be undertaken by incorporating the scenarios into the Munich Metropolitan Area model that is currently under development by the research group, Professorship of Modeling Spatial Mobility, at the Technical University of Munich. The research group is currently developing an integrated land use and transportation model by linking the land use model SILO with the transport model MATSim. The study will focus on revealing the expected travel demand with the Northeast development and show who is moving and where.

### Intermediary results and evaluation:

The student will present intermediate results to the mentor(s) (Prof. Dr.-Ing. Rolf Moeckel and Dr. Ana Tsui Moreno Chou) in the fifth, tenth, 15th and 20th week. The student will submit one copy for each mentor plus one copy for the library of the Focus Area Mobility and Transport Systems. Furthermore, the student will provide a PDF file of the master thesis for the website of this research group. In exceptional cases (such as copyright restrictions do not allow publishing the thesis), the library copy will be stored without public access and the PDF will not be uploaded to the website.

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The student must hold a 20-minute presentation with a subsequent discussion at the most two months after the submission of the thesis. The presentation will be considered in the final grade in cases where the thesis itself cannot be clearly evaluated.

Prof. Dr.-Ing. Rolf Moeckel

# Abstract

Forecasting and investigating the effects of an urban development project is of great interest to most developed cities. Topics of interest to both the city planners and new tenants are generally, affordability, accessibility, sustainability, attractiveness and vitality. These properties are mostly achieved with the correct land use plan and an efficient transport network. Fortunately, land use and transport planning for such urban development projects can be modelled before any implementation is actioned.

To assess and ascertain anticipated future effects of urban developments, an integrated land use and transport model can be used. This thesis uses such a model to forecast the effects of an urban development in the north-eastern suburbs of Bogenhausen and Trudering-Riem in Munich, the state capital of Bavaria, Germany. The project goes by the name of the 'Northeast Munich' and several scenarios are tested to find the most attractive conceptual layout for the area and more importantly to assess the impacts of the urban development.

The integrated modelling suite used for the Northeast Munich study is the Munich Metropolitan Area model that is currently under development by the research group, Professorship for Modeling Spatial Mobility, at the Technical University of Munich. The research group is currently developing an integrated land use and transportation model by linking the land use model SILO (Simple Integrated Land-Use Orchestrator) with the transport model MATSim (Multi-Agent Transport Simulation). This thesis naturally focuses on the main modules for the integrated models thus including substantial efforts to prepare and allocate data correctly before any modelling is initiated.

The results of the three scenarios are compared to the base scenario in terms of their changes in population, population by income, number of dwellings, dwelling occupancy, average price, number of jobs and accessibility levels. Consequently, the results show an increase in population, number of dwellings and number of jobs in the development scenarios compared to the base (do nothing) scenario. The dwelling occupancy rates show that many households relocate into the Northeast and that they mostly consist of people in the lower income groups. Average prices for the Northeast are slightly higher with the development scenarios, however this is thought to be an error with exogenous data. Similarly, the accessibility of the Northeast could not be measured suitably for the development.

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To all my friends, old and new, near and far, for their undying compassion and motivation. And finally, to my family, Kiyeul Kim, Mijong Kim and Jisuk Kim, on the other side of the world, much love and thanks for your constant support, prayers and most importantly, for making everything worthwhile.

# Declaration Concerning the Master's Thesis

I hereby confirm that the presented thesis work has been done independently and using only the sources and resources as are listed. This thesis has not previously been submitted elsewhere for purposes of assessment.

Munich, November 7th, 2017

Ji Yeun (Ruby) Kim

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# List of Abbreviations

| | |
|---|---|
| CoM | City of Munich |
| DUPBR | Department of Urban Planning and Building Regulation |
| GIS | Geographic Information System |
| LUTI | Land Use Transport Interaction |
| MATSim | Multi-Agent Transport Simulation |
| MMA | Munich Metropolitan Area |
| MSM | Modeling Spatial Mobility |
| MVG | *Münchner Verkehrsgesellschaft* 'Munich Transport Company' |
| MVV | *Münchner Verkehrs-/Tarifverbund* 'Munich Transport and Tariff Association' |
| Northeast, the | Urban development area under investigation |
| OSM | OpenStreetMap |
| POI | Point of Interest |
| Professorship, the | The Professorship for Modeling Spatial Mobility |
| S-Bahn | *Stadtschnellbahn* 'Urban rapid rail' |
| SILO | Simple Integrated Land-Use Orchestrator |
| Study Area, the | Munich Metropolitan Area (Augsburg, Ingolstadt, Landshut, Munich and Rosenheim) defined by the Professorship |
| TCRP | Transit Cooperative Research Program (Report 48) |
| TOD | Transit-Oriented Development |
| TUM | Technical University of Munich |
| U-Bahn | *Untergrundbahn* 'Underground railway' |
| VEP | *Verkehrsentwicklungsplan* 'Transport Development Plan' |

# 1 Introduction

The imminent need for quality urban development is a frequent topic in successful and attractive cities. Such urban development requires enormous amounts of both time and money to achieve and is usually difficult to alter once constructed. Therefore, it is most important to ascertain the potential impacts of such urban developments before making permanent establishments. To investigate these impacts, planners need to understand how, where and why people will choose to live, work and travel.

Efforts to answer these questions by using land use and transport integrated (LUTI) models exist since the 1960's (Orcutt *et al.*, 1961; Lowry, 1964; Echenique, Crowther and Lindsay, 1969; Forrester, 1969). The idea blossomed since Hansen (1959) announced the relationship between accessibility and land use, and the significance of thinking about demographics and mobility together. LUTI models have since been continuously recognised as the best practice when it comes to city planning. In general, LUTI models consist of a land use model containing the population and employment data which is used to generate travel demand. This is then fed into a transport model which uses the travel time, also known as skim matrices, between locations to calculate accessibility. The concluding effect of the land use properties and travel time matrices are then looped back into the land use model. The result is a loop cycle between the two models which is referred to as the integrated model.

The literature on LUTI models are mainly focused on the design of the land use model and its linkage to a transport model to create the loop cycle. Many different land use models have been used throughout the years, all for similar purposes. Although many detailed aspects improved over time, the literature review shows that the general land use modelling framework has been left unchanged.

The *Referat für Stadtplanung und Bauordnung*, 'Department of Urban Planning and Building Regulation' (DUPBR) from the City of Munich (CoM) is in the process of developing the final conceptual design for the urban development in the 'Northeast Munich' project (the Northeast). The project is regarded as one of the largest remaining potential for the future development of settlements in Munich. The plan is to undergo a multiple staged approach to decide upon the final structural concept, after which, steps for further implementation will be commissioned. The approach involves a careful investigation of the development landscape, settlement and transport.

## 1.1 Outline

This report is structured in the following order:

- Chapter 2 provides a historical introduction and insight into LUTI models including the state-of-the-art.
- Chapter 3 explains the approach taken for the successful completion of the study.
- Chapter 4 reviews the Munich Metropolitan Model especially focusing on the land use model SILO
- Chapter 5 gives an overview of the current urban status of the area of interest (the Northeast) and introduces the proposed scenarios.
- Chapter 6 describes the modelling specifications used for the integrated analysis.
- Chapter 7 contains the workings of the land use model, the following input dataset used and the development timeline.
- Chapter 8 contains the workings of the transport model and the transport network applied for the analysis.
- Chapter 9 explores and discusses the modelling results. And;
- Chapter 10 acknowledges any limitations of the model and the scenario forecasts, suggests further research and concludes the study.

# 2 Land Use and Transport Integrated Models

## 2.1 History of Land Use and Transport Integrated Models

Land use and transport integrated (LUTI) models were primarily founded in the 1960s and has since been of interest in the land use planning and transport planning sectors to date. Initially, Hansen (1959) introduced a tool for the purposes of exploring accessibility patterns within a metropolitan area and subsequently used it for planning. The process involved a distribution of the anticipated future population into the study area. Consequently, Hansen found that the existence of public transport points accelerated development in the vicinity of the stops, thus, showing the relationship between the development of land use and transport.

Correspondingly, Lowry (1964) introduced a first-generation land use model of Pittsburgh in Pennsylvania, for the purposes of using it as a tool to guide urban planning and development. The model takes into account the complex interrelationships between land use, the transport network and the activities. This demand driven model uses an iterative process to forecast. Similarly, Echenique, Crowther and Lindsay (1969) developed the MEPLAN model using Lowry's first-generation model as a starting point. Two sub-models, the stock model and the activity model, is used to create a simple static model using data from Reading, England. The stock model uses floor space as the measure for demand, the transportation network and any other constraints for all basic activities. The activity model includes the population and the service activities which are constrained by the transportation network and the amount of floorspace available. Forrester (1969) also states the importance of integrating land use and transportation in an urban sense. His theory of urban interactions describes how the rise and fall of population in certain urban areas can cause either an increase or a decay of transport and public services. This is shown through his model, known as the second LUTI model, built on what he thinks as the major parts to a city: three classes of population, three types of housing and three types of industry. At a similar time, Orcutt *et al.*, (1961) thought to exercise microsimulation modelling which meant simulating individual people, whilst others were using aggregate population values. Another type of approach was suggested by Wilson (1967) where a simple gravity model is used for spatial distribution. The model had been developed with the theory of Newton's law of gravity to create an entropy model. This model tries to reach an equilibrium by balancing the overall entropy of activities for all zones.

Further into the 1980s, De La Barra and Rickaby (1982) describes a mathematical LUTI model called the TRANUS model. Having been slightly influenced by Lowry's model (Lowry, 1964), TRANUS uses energy use to evaluate land use patterns. The model was used to compute and compare different regional configuration scenarios with a base scenario. Likewise, Wegener (1982) simulated a wide range of possible economic and demographic changes of Dortmund with his fully integrated IRPUD model. IRPUD worked microscopically where each household's choice of dwelling was modelled individually using dwelling costs and the distance to work. Meanwhile Putman (1983) came up with ITLUP. One objective of the study was to discuss and look into the consequences that result from the integration of land use and transportation models. Subsequently, Putman critised the separation of a complex system into smaller sub-groups or components. Thus in contrast, ITLUP was designed in a way in which each major sub-model is developed to allow the reader to identify the most important elements.

Similarly, Martínez (1996) uses a land use model MUSSA with a four-step transport model designed for Santiago called ESTRAUS. In this model, the bid-choice theory is applied to mirror the competitive property market, thus includes the availability of land and a theoretical assumption of development patterns. Once again, the land use model MUSSA provides the location of activities such as dwellings and workplaces whilst the transport model ESTRAUS measures economic access. As a basis to this, a regional forecast of the population and activities are used. Importance of such an alignment of city plans and forecasts has also been talked about by Miller, Kriger and Hunt (1999). As published in the Transit Cooperative Research Program (TCRP) Report 48 as a guideline for the implementation and use of LUTI models, the significance of lining up plans of all different sizes of urban areas has been stressed. Furthermore, LUTI models were recognised as the best way forward for analysing interconnections between and within regions with the core fact that land use and transport are closely related. Another land use model is DELTA which has been designed to be integrated with any suitable transport model (Simmonds, 1999). DELTA shows the changes in the urban area of the city of Edinburgh (Scotland) over a one to two year period. The main idea behind the model is to estimate the spatial changes in household locations, employment growth, the competitiveness of the property market and the population's employment rates. The decisions are made on a set of accessibility and environmental measures from the coupled transport model.

Moving into the 2000s, even more models have been designed or first-generation models, enhanced, such as UrbanSim, ILUTE, Metroscope, PECAS, PUMA, simDELTA, LUSDR and more (Waddell, 2000, 2002; Miller and Salvini, 2001; Conder and Lawton, 2002; Hunt and Abraham, 2003; Ettema *et al.*, 2007; Gregor, 2007; Simmonds and Feldman, 2007). Naturally as cities became denser and private vehicle ownership peaked, the demand for a more convincing land use and transport planning tool grew. Likewise, there was a need to make the best prediction to assist practitioners to decide upon the right investments in urban development, utilities and infrastructure. This is precisely what motivated Waddell (2000) to design the UrbanSim model and make implementations for Hawaii, the Oregon metropolitan area and the Greater Wasatch Front Region of north-central Utah. UrbanSim models microscopically for individuals and is integrated with a four-step travel demand model. The main difference of UrbanSim was the dynamic behaviour model of the real estate market. This model uses the changes in demand, supply, the corresponding prices and an annual time schedule to simulate fluctuations. Soon after Miller and Salvini (2001) developed the ILURE modelling system which is a fully microsimulation land use modelling suite. The model focuses on interaction between land use and urban transport by representing the population in decision-making units. In addition, the anticipated environmental effects of the interaction are assessed. In doing so, the authors found that it changed their way of viewing urban systems and realised that it is in the foundations of the assumptions that make up the essence of the model.

Another LUTI model developed at a similar time is the MetroScope model for the regional analysis of Portland, Oregon (Conder and Lawton, 2002). The model was used to test various regional growth scenarios and to use the results to create new plans. During the scenario testing phase, it was found that MetroScope responded well to different land use and transport plans that arose from different policy choices. Furthermore, the model excelled at producing data for sub-parts in the real estate market. Similarly, Hunt and Abraham (2003), came up with one of the most applicable bid-rent models to date called the PECAS model. The PECAS model simulates spatial economic systems with a microscopic land use model for several regions in North America. The simulation uses floorspace supply with demand to model the competition for developable land. Like other LUTI models, individual household characteristics are used to generate household relocation decisions. Using the PECAS model, Clay *et al*. (2010) undertakes a land use and transport integrated modelling exercise by using the development project in Montgomery, in Alabama, as a case study. The motive was to be able to respond to frequent changes in national policies while keeping land use plans and transport plans consistent with one another. Thus, a wide range of scenarios were tested and, alongside the forecasting, the study acted as an initiator for others interested in developing an integrated model for a small to medium sized metropolitan region.

Likewise, the PUMA model used the theory of individuals being the prime initiator of land use change (Ettema *et al.*, 2007). PUMA is another complete suite of multiple agents and urban processes. The model is made up of a list of actors that are characterised with modules. The modules used are the land conversion module, households module and the firms module. In the same year, Gregor (2007) developed the LUSDR model for the Rogue Valley metropolitan area in Jackson County, Oregon. Gregor recognises the usefulness of LUTI models however realises the unfortunate complexity of these models and their large requirements in labour and data to build them before any implementation is possible. For this reason, LUSDR is built with a simpler structure and less data requirements whilst still including the main land use behaviour principles. Also micro-simulating, the model generates a synthetic population with basic demographics. Household characteristics determine dwelling choice and the workers of each household adds to the allocation of employment. The land supply and demand of each zone determines the availability of land for both dwellings and jobs.

In the same year, Wagner and Wegener (2007) introduced the idea of integrating a microscopic land use model with a transport model that was also microscopic. Until now, all models were equipped with an aggregate transport model until the ILUMASS project commenced. Although the integration of the two microscopic models did not achieve operational status, substantial progress had been made for the interface between the models. Nevertheless, Waddell *et al.* (2010) later improved the initial UrbanSim model to fully micro-simulate land use at a parcel and building level. UrbanSim was combined with a microsimulation activity-based travel model for San Francisco in California, thus achieving the first fully microsimulation LUTI model. The activity based travel model used in conjunction with UrbanSim was the San Francisco SF-CHAMP. The parcel accessibility levels calculated with the SF-CHAMP were used to predict and update household and employment locations. In the same way, others added improvements to their models. Simmonds returned with an advanced version of the DELTA model called the SimDELTA (Simmonds and Feldman, 2007). Improvements to the initial setup are seen as Simmonds and Feldman stresses the importance of thinking of study areas in context to their surrounding environment. Particularly, this cannot be ignored in cases where cities and the subsequent urban areas are relatively close by, leading to more activity between major urban areas. Likewise, urban areas are evaluated at a finer resolution meaning that initial strategic level applications are outdated.

More recently, Moeckel (2011) used household budgets to simulate dwelling choice and transport in the land use model SILO. The model assumes that households generally do not exceed their respective travel budget and thus balances out the costs between monthly dwelling costs and travel time. This land use model was later integrated with the transport model MATSim (Horni, Nagel and Axhausen, 2016) and an initial version implemented for the state of Maryland in the United States (Ziemke, Nagel and Moeckel, 2016). At a similar time, Parvaneh, Arentze and Timmermans (2011) developed a model to estimate changes with recent developments in personal technologies. The popular use of advanced information and communication technologies provide real-time travel information for each user and thus is thought to change travel patterns. For this reason, the model uses dynamic behavioural patterns of travellers and their informed actions in both destination choice and route-choice.

Another innovative application of LUTI models is to use them as a tool for assessing more dynamic and unknown events of the future (Kii *et al.*, 2016). Kii *et* al. predicts the future requirement of creating more flexible LUTI models to simulate with unpredictable events. Such events may include the insufficiency of energy, climate change and environmental changes, social conflicts and – once again – new technologies, including personalised travel information, shared driving, driverless cars and autonomous vehicles.

## 2.2 Overview of Models

Due to the popularity of land use and transport integration and the continuous development of these models for the past sixty years, overviews of such models and guidelines for good practice exist. Firstly the TCRP Report 48 prepared by Miller, Kriger and Hunt (1999) summarises the necessity for research into this sector. The need to meet future demands to find solutions for the effects caused by changes in mobility, environment and energy onto places and land use is essential. Thus, the report provides a guideline for the implementation and use of LUTI models; And describes what LUTI models should be capable of achieving by picturing the 'ideal' LUTI model concept. From the document, LUTI models should be "theoretically sound, result-driven, responsive to transit issues and other urban transport planning, cognizant of the regional, state, national and global demographic and economic interrelationships, practical to operate, sufficiently flexible and presentable" (Miller, Kriger and Hunt, 1999). Furthermore, LUTI models must consist of the following modules: land development, location choice, activity/travel and automobile ownership. After an assessment of six operational LUTI models, the characteristics of an 'ideal' LUTI models come as a checklist called the 'Components of the Six Capacility Levels,' provided as a guide to the reader. Accompanied with the checklist is a matrix of LUTI models and their modelling capabilities.

Similarly, Wegener (2004) provides an extensive overview of twenty LUTI models that were then available and operational. Wegener especially focuses on the theoretical background and empirical studies that gives the models their abilities to test for both land use and transportation policies. An evaluation of how they assess the impacts of those policies follows. This is done by comparing the models in terms of the following criteria: comprehensiveness, model structure, theoretical foundations, modelling techniques, dynamics, data requirements, calibration and validation, operationality and applicability. The focus is to see how correctly the models represent the interrelationship of land use dertermining traffic flow and the changes in the transport network changing land use variations. Finally, the usefulness of the models are analysed for when changes in policies are made for urban areas.

Correspondingly, Hunt, Kriger and Miller (2005) reviews six LUTI modelling frameworks, focusing on the state-of-the-art. The review included the frameworks' physical properties, decision making processes and their methods of implementation. Consequently, none of the frameworks met all of the requirements of an 'ideal' framework perfectly, but it was seen that many represented an explicit change in policy quite well. Furthermore, the movement of these frameworks, into considering for the more unpredictable environments are evident. For this reason, a solidification of the foundational behavioural theories is appropriate for the future.

Most recently, Acheampong and Silva (2015) summarises 60 years of publications on the integration between land use and transportation in their review paper. On these foundations, further recommendations for future research is found. The four major themes for improvements are summarised as: challenges from disaggregation; challenges with integrating activity-based travel demand models into land use and transport integrated models; measuring accessibility; and integration of the environment into land use and transport integrated models.

The history of LUTI models show how the major overarching motivation, development and integration of such models are essentially unchanged during the 60 years. Most initiate a LUTI model for the purposes of forecasting future land use and transport development for a specific urban region or regions. Usually the development of the regional models include the main modules of the known population, employment and land availability figures. Then the integration involves the land use model producing travel demand which feeds into an aggregate or an agent-based transport model. Finally the transport model generates the travel distances and times (skims), used by the land use model to quantify accessibility rates and corresponding choices for dwellings and jobs once again. This loop process has been presented as a land use and transport feedback cycle by Wegener (1994), as shown in Figure 1.

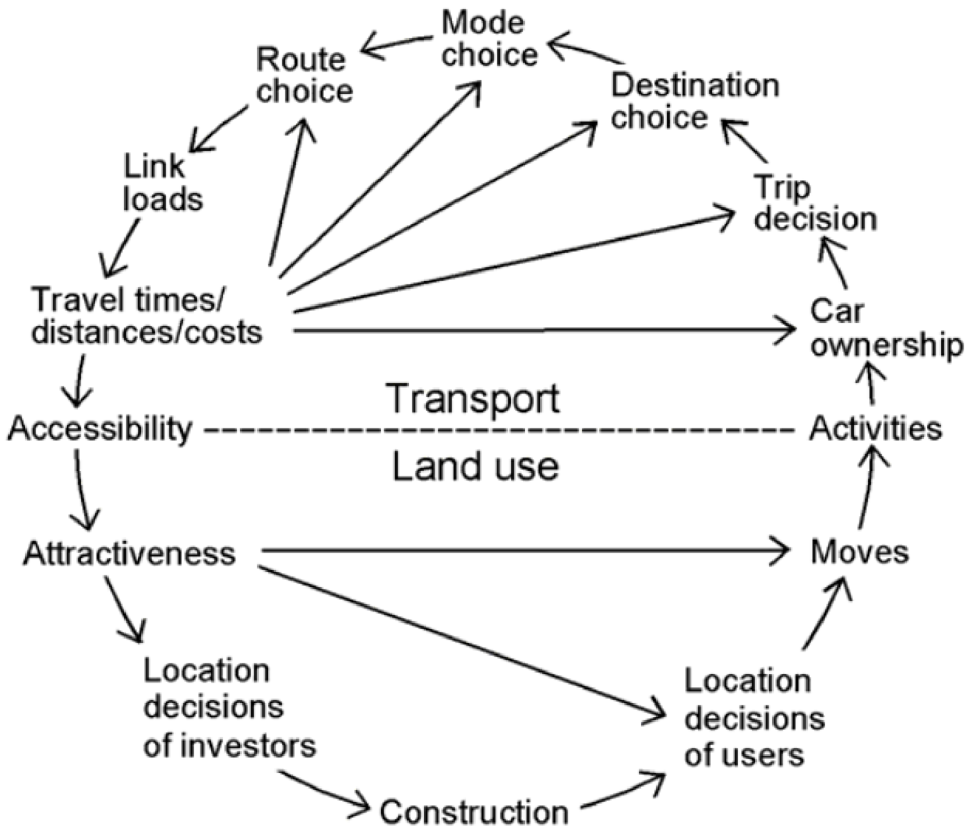



Figure 1 Land Use and Transport Feedback Cycle (Wegener, 1994)

## 2.3 Objectives

LUTI models are an efficient and theoretically sound tool to assess effects caused by urban development including land use and transport changes. The primary goal of this thesis is to forecast the land use and transport impacts of the three scenarios under consideration for the Northeast urban development. The integrated suite of the Munich Metropolitan Area (MMA) model is used for the analysis. A secondary goal is to find differences between the land use and transport effects between the three scenarios and consequently find what each scenario may bring.

It is expected that all three scenarios will show that the Northeast is an attractive area to live and work with the opportunities created by the urban development. An increase in population, number of dwellings and number of jobs is expected. Furthermore, the large number of additional dwellings is expected to partially relieve the pressure on the current housing demand of Munich. This will decrease the average price (monthly rent) of dwellings. Furthermore, an improved transport network will help to achieve higher accessibility levels of the area for both private cars and public transport. A higher accessibility adds to the attraction of the area thus, adding to the attractiveness of the Northeast. It is expected that most of the dwellings created with the scenarios will become occupied at a fast rate.

There has been an immense amount of research completed in the topic of integrating transport and land use in urban environments. Likewise, there has been many tests of using these tools and implementing them to real life scenarios. Principally, producing any results with the integrated model of SILO and MATSim for the defined MMA Study Area contributes to this field of study. The fitting of appropriate data for the area selected makes the model, and thus the study, unique in itself. Furthermore, this study contributes to this body of research by completing a scenario analysis using the integrated model of SILO and MATSim which has not been completed before with the integrated suite. In doing so this study provides additional steps to further refine the suite whilst adding to the scenario analysis discussions of the Northeast Munich urban development project.

# 3 Approach

An integrated modelling suite is used to compare the three alternative scenarios formed by the CoM. The approach requires the following main tasks and underlying sub-tasks:

- Munich Metropolitan Model
  - Review of the land use model SILO and the transport model MATSim
- Northeast Munich
  - Review the City's motivation and the existing environment
  - Examine the scenarios proposed by the CoM
- Modelling Specifications
  - Decide on the modelling specifications for the integrated modelling
- Land use model
  - Determination of scope and availability of data
  - Specification of scenario input variables and parameters
  - Deciding upon a development timeline
  - Preparation of the dataset for the forecast
- Transport model
  - Determination of scope and availability of data
  - Specification of scenario input variables and parameters
  - Preparation of the dataset for the forecast

# 4 Review of the Munich Metropolitan Model

The assessment will be undertaken by incorporating the scenarios into the MMA model that is currently under development by the research group, Professorship for Modelling Spatial Mobility (the Professorship, MSM), at the Technical University of Munich (TUM). The research group is currently developing an integrated land use and transportation model by linking the land use model SILO (Simple Integrated Land-Use Orchestrator) with the transport model MATSim (Multi-Agent Transport Simulation). A short history of SILO is described followed by an introduction to MATSim.

## 4.1 The Build-up to SILO

Like most models, SILO is not an instant creation. Many details of the model have been thought of quite a time before the model came into action. From the literature review on SILO one can suspect the initial starting point that led to SILO is from the creation of the synthetic population by Moeckel, Spiekermann and Wegener (2003). The need for more detailed data about a city's population for the purposes of activity-based models was the driving factor for the creation of a synthetic population. Moeckel, Spiekermann and Wegener (2003) found that LUTI models should be capable of modelling for the disaggregate population and workplaces in order to successfully use activity-based models for the new environmental debate and more detailed neighbourhood planning. Thus, a Monte Carlo microsimulation methodology was adapted to create a synthetic population using the known aggregate population and employment data. The synthetic population embodies individuals, their households, workplaces and basic demographics that are used with decision making models. Household addresses were also created using land-use data which were available at the raster level with the use of Geographical Information System (GIS) methods. The implementation of creating a synthetic population using the above method has been applied to the city of Netenya, Israel and Dortmund, Germany.

Afterwards, the inefficiency of initial land use models led to the creation of a model called SEAM (Moeckel, Costinett and Weidner, 2008). SEAM was created due to many integrated models resulting as a complex academic tool and consequently not reaching the stage of becoming an easy to use planning tool. Moreover, only a number of transport models are capable of integrating with complex land use models. In constrast, SEAM uses only a number of input data and simple calibration methods. The new model simulates the population, employment, work trips and flow of goods with a faster matrix balancing technique. Using the data from the initial study area of the Ohio Statewide Modeling Project (OSMP), the overall purpose of creating a simple land use model for integration was met.

Not long after, and due to similar restrictions of many complex land use models at the time Moeckel (Moeckel, 2011, 2015) built the simple but robust land use model SILO. SILO was built to integrate with both aggregate and disaggregate transport models. Each person and household is simulated individually for households and the real-estate market with the intention to further expand into the areas of simulating employment and non-residential land availability. The model introduces an energy constraint framework where households do not exceed their household and travel budgets. Households are required to balance their expenditure between dwelling costs and travel costs (time and other costs) thus, decisions to move to a more appropriate dwelling (less costly dwelling) or area (closer area to commute to work) can be triggered. The initial pilot study was made for the Minneapolis/St. Paul Metropolitan Area in Minnesota.

Again, Moeckel (2017) explains how the integrated land use model SILO can be more representative of real life household relocation decisions. This is achieved by the aforementioned constraints for housing price, commuting times and a household's transportation budget in terms of time and money. This is because SILO is based on the fact that 86% of all workers commute for less than 60 minutes to work and 99% commute less than 120 minutes to work (2007-2008 Household Travel Survey for the Baltimore/Washington region). Furthermore, SILO assumes a constant travel time budget, which has been seen to undergo almost no change throughout history (Zahavi, 1974). This travel time budget is approximately 18% of the net income of a household according to a Consumer Expenditure Survey in the United States (U.S. Bureau of Labor Statistics, 2017).

Shortly after Moeckel, Avin and Welch (2014) integrated the land use model SILO with the transport model MSTM to simulate land use and transport synergies for the State of Maryland. The integrated modelling suite has been used to test the Transit-Oriented Development (TOD) policy of the Maryland Department of Planning and the Maryland department of Transportation. A new light rail line was proposed to connect residential areas in Maryland and thus the model was used to ascertain movements in and around the areas that will consequently have good access to the new line. Particularly, the type of households, by income group, moving into the area were observed and the amount of public transport usage in the area were also of interest.

More recently, Dawkins and Moeckel (2016) used the integrated model of SILO and MSTM to undertake a scenario study of the effects of TOD in the Washington, D.C. metropolitan area. TOD policies were introduced in the intentions to relieve various issues of the city such as congestion, pollution and urban poverty; particularly to provide lower income households with more accessibility to jobs. However, by doing so land and dwelling prices may increase, transferring lower income households to an again less accessible area. This outcome is termed 'transit-induced gentrification' and thus the real effects of the policy was of interest. The three scenarios tested for were the TOD affordable housing scenario, the compact development scenario and the combined scenario. Although SILO results were unavailable, historical assessment of the area showed that transit-induced gentrification is evident in the study area.

Once again, the integrated model of SILO and MSTM was used to test the potential impacts of a number of Smart Growth policies and transport policies in the State of Maryland (Moeckel and Lewis, 2017). The policies advocates for a targeted funding scheme for the growth and investment in the State's Priority Funding Areas and the existing urban areas. Although the scheme inhibits funding in transportation infrastructure that are not in the prioritised areas, there are no detailed guidelines for the integration of the two policies which may lead to a more precise prediction of the overall Smart Growth policy.

Further to the integration between SILO and MSTM, Ziemke, Nagel and Moeckel (2016) introduced the first steps of integrating SILO with the agent-based transport model MATSim, proving the models compatability with a disaggregate transport model. The transferring of agent-information for both directions between SILO and MATSim is explained and discusses how the new LUTI suite can be used for new research topics.

## 4.2 SILO Workflow

The SILO workflow starts with the synthetic population holding the data for the population (households and persons), dwellings and jobs (silo.zone, 2016). The synthetic population has been developed by the Professorship for the MMA, formed from a collection of official data sources. These include, the Household Census microdata (from the German State Statistical Office), and the more aggregate data from the German GENESIS-Online database, the German Household Census and the European CensusHub. As the micro-census data provides no location detail it is distributed amongst the MMA using the more aggregate data available for counties and municipalities. The MMA includes five central cities (Augsburg, Ingolstadt, Landshut, Munich and Rosenheim). The total population of the MMA is approximately 4.5 million people or 2.1 million households. Dwellings are then defined by their type, size and quality. Jobs are classified into ten job types. The final collection of the households, persons, dwellings and jobs are used to simulate demographic changes and real estate development.

***Demographic Changes***

Demographic changes include aging, giving birth to a child, leaving parental household, getting married, getting a divorce, death, move and immigrate/outmigrate. Each demographic change is associated as an 'event' and is accompanied with a model container. The model container comprises of the mathematical model behind triggering each of the events.

The models for death, birth, leaving parental household, getting married and getting a divorce are relatively simple. They are a set of defined probabilities depending on the characteristics of the individual, such as gender and age, for each of the possible events. Immigration and out-migration models are also simple as they are set up using the total population as a control variable. The trickier change is the relocation model where households decide to either move or stay by comparing dwellings and regions.

The evaluation of dwellings depends on the household size, household income, and the details of dwellings, including: price, size, quality, accessibility by car, accessibility by public transport, school quality, crime index, travel time to job(s) and total travel costs. Travel costs is a combination of the price, commute time(s) and any other expenses.

The region selection model is also a part of the move model where each household decides to either move to another region or stay in the current region. This model depends on the regions median dwelling price, regional accessibility by income group, school quality by income group, crime rate by income group and also the level of segregation by income group.

The accessibility model reads the travel times from and to all zones (skims) for either private car or public transport and uses Hansen's (1959) accessibility calculation. The calculation returns a scaled unit between 0 and 100, where 0 is the least accessible zone in the area and 100 is the most accessible.

***Real Estate Development***

Real estate development includes events such as build new dwellings, renovate dwellings (increases rent), dwelling deterioration and demolish dwellings. The developers' decision to construct new dwellings depends on the demand for more residential floorspace. The renovation model and the demolition model depends on the current quality of the dwellings. Both use probabilities to renovate and demolish dwellings. There are five types of dwellings:

1) SFD – Single Family household Detached
2) SFA – Single Family household Attached (or townhouse)
3) MF234 – Multi Family duplexes and buildings of two to four units (excluding those that are attached or townhouse)
4) MF5plus – Multi Family houses with five or more units
5) MH – Mobile Home

Additional changes simulated by the real estate development model is the pricing model. The pricing model returns the rent price or the monthly costs of the dwelling. Rent prices are initially based on the land price and change depending on the occupancy levels of the current dwellings. In short, an increase in demand will increase the price and vice versa.

***Household Relocation***

The decision to move to a new dwelling is made after a comparison of the calculated utility values for all possible dwellings/regions compared to the current dwelling/region.

## 4.3 MATSim

The agent-based transport model MATSim (Horni, Nagel and Axhausen, 2016) is a powerful yet fast large-scale traffic simulator that has been often integrated with a land use model (Hao, 2009; Nicolai, 2013; Dobler, Horni and Axhausen, 2014).

The model simulates an individuals typical day by reading the dwelling location, activity locations and the consequent trips in between activities (matsim.org, 2017). This typical day is run repetitively for a stated number of iterations in which the individuals test various routes and travel options. The repetition consequently achieves a 'relaxed' or 'noisy' equilibrium where individuals decide on their most attractive travel methodology after a series of evaluation and memorizing of previous experiences.

The flowchart summarising the integrated models of SILO and MATSim is shown in Figure 2.

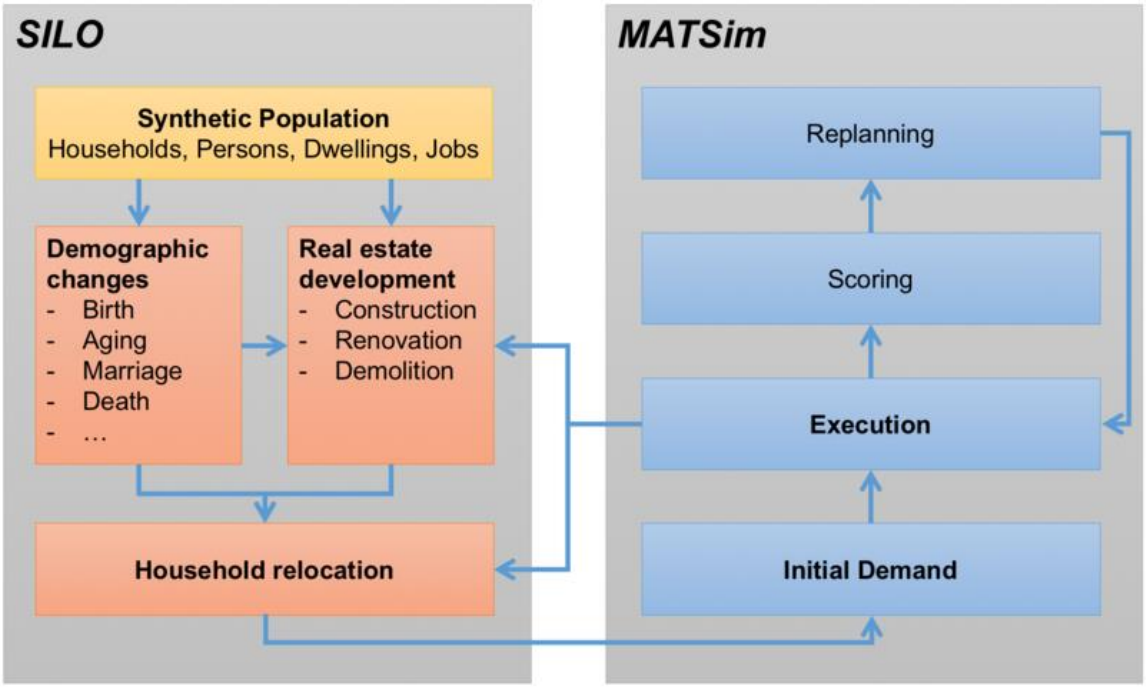



Figure 2 SILO/MATSim Integration (Assistant Professorship of Modeling Spatial Mobility, 2017b)

# 5 Northeast Munich

## 5.1 Motivation

With the future population of Munich to reach 1.8 million by 2030 (Landeshauptstadt München, 2017), urban development to accommodate for the anticipated demand is vital. As part of the solution, the Department of Urban Planning and Building Regulation (DUPBR) from the City of Munich (CoM) are currently investigating concepts for developing the Northeast area of Munich. The 600 hectares of land under consideration is situated on the east of the airport line (S-Bahn line S8), at the Bogenhausen and Trudering-Riem area. Development is to take place gradually in the coming decades and the DUPBR have proposed three possible scenarios.

## 5.2 Existing Environment

The existing environment of the Northeast is a sparsely populated, rural research area located in the municipalities of Bogenhausen and Trudering-Riem. The area is bound in the west by the S-Bahn line S8 between S-Bahn stops Daglfing, Englschalking and Johanneskirchen. The area sits on the border of the city boundary on the north-east and the former freight line, the Lebermoosweg. In the south, the area is bound by Töginger Straße. Another potential boundary of interest is the Hüllgraben, which is an artificial water stream that runs vertically through the eastern section of the area of interest.

The existing private and public transport network of the Northeast and their respective travel demands are shown in Figure 4. The area sits in between the major roads, the *Bundesstraße* 'federal highway' M3 to the north and *Autobahn* 'federal motorway' Töginger Straße to the south, both connecting to the city centre. The site is located on an attractive area in terms of public transport as the S-Bahn line S8 runs north-south on the western border, along with S2 running west-east on the southern border.


Figure 3 Northeast Munich Development Boundary – Munich City (maps.google.com, 2017)

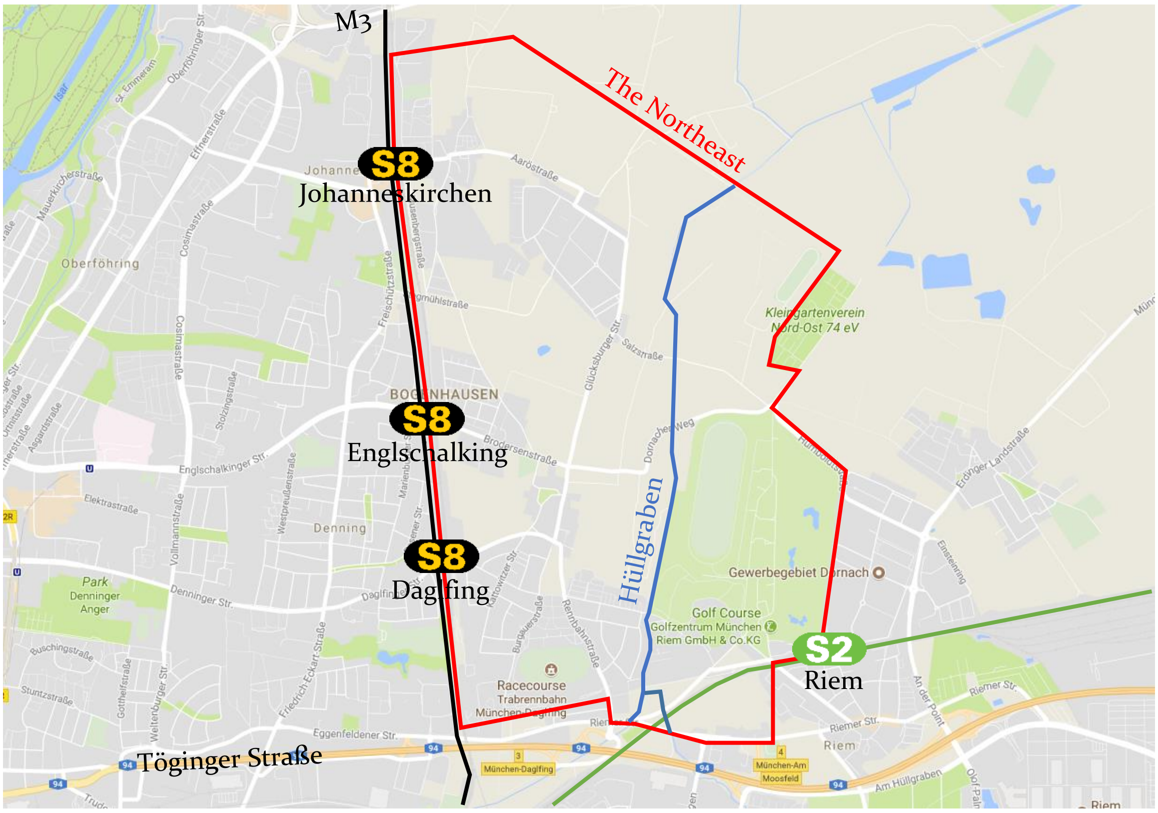



Figure 4 Northeast Munich Development Boundary (maps.google.com, 2017)

## 5.3 Introducing the Scenarios

Three scenarios are under consideration for the Northeast. Each compose of a different overall theme, a slightly differing population and employment target and a different amount of land the development is to occupy.

***Scenario 1***

Firstly, scenario one, called 'The Bead Chain,' promotes the development of new settlements predominantly along the existing S-Bahn Line (S8) stations, Daglfing, Englschalking and Johanneskirchen. The idea is to base the development around the existing settlement structures and to expand them into separate quarters, filling the area between the S8 line and the Hüllgraben. The green area to the east of the Hüllgraben is labelled a natural boundary and thus preserves the area from the Hüllgraben to the eastern city boundary. The extension of the U-Bahn line U4 is proposed with a new stop east of the S8. With a population potential of approximately 29,100 people and potential number of jobs of approximately 7,900, this scenario offers the least room for development.

***Scenario 2***

Scenario two, known as the 'New Neighbourhoods at the Hüllgraben,' is a concept that bridges the existing settlement structures at Dagling and Englschalking from the west with Bogenhausen and Riem to the south-east. This involves a potential extension of the U-Bahn line U4 south-east towards Messestadt West via Riem. This possible extension of the U4 is the central transport element. The overall theme of this concept is to create very compact residential districts on both sides of the Hüllgraben to accommodate for approximately 30,100 people and 9,400 jobs. This results in a new connection between Englschalking and Messestadt, creating a new centre at the Hüllgraben. This scenario achieves the largest population numbers out of the three scenarios.

***Scenario 3***

Lastly, scenario three is named the 'Coastline' due to the shape of the boundary of the development. Three green corridors are placed in between the settlement structures providing an interlinking of the city and landscape. The main idea behind this concept is to make the green areas as directly accessible by people as possible. The new settlements are to expand north and east of the area and thus connects to existing neighbouring communities such as Unterföhring and Dornach. Also, similarly to scenario 2, a possible extension of the U-Bahn line U4 towards Messestadt West via Riem is proposed. This scenario is expected to also span over both sides of the Hüllgraben, and accommodate for approximately 29,800 people and 10,500 jobs, hoping for the largest employment numbers out of the three scenarios.

Detailed conceptual layouts and quantitative features can be found in Appendix A.

# 6 Modelling Specifications

Forecasting the future land use and transport impacts of the Northeast involves the integrated modelling exercise between SILO and MATSim. In order to attain successful results a thorough review of the main data inputs for SILO is completed. Similarly, new transport networks, both private and public, are created for each of the three scenarios. The specifics for preparing the integrated modelling between SILO and MATSim are explained.

SILO is run yearly from 2011 to 2050, whilst MATSim is run in years 2012, 2030 and 2050. The zone system recreated for the Northeast is constant from the start year 2011 to the end year 2050. The employment estimate and general forecast carries through the modelling years with scenario employment additions. New dwellings with the development scenarios are also added exogenously to the underlying real estate development model. Both the addition of employment and dwellings follow the development timeline defined in Chapter 7.4 which uses the phases proposed by the DUPBR; The implementation years are 2020, 2030, 2040 and 2050.

Unlike the inputs for the land use model, transport network changes are made once in the year 2030, where the initial network is overwritten by the new network. The new transport network is a merged network of the initial and the new private and public transport networks. The new links with their respective capacities and speeds are included for both the private transport network and the public transport network.

To achieve reasonable run times the population is simulated in part. SILO simulates five percent of the population. MATSim then repetitively simulates a typical day for these individuals for 50 iterations to achieve a 'noisy' equilibrium. Afterwards the most attractive travel route is chosen by each individual. A complete model run of the integrated model takes approximately 34 hours on an average desktop computer.

# 7 Land Use Model

## 7.1 MMA Study Area

The Study Area for the Munich Metropolitan Area consists of Munich, Augsburg, Ingolstadt, Landshut and Rosenheim. The extent of the Study Area had been defined by the Professorship by analysing commute patterns of people that commute to the Metropolitan Area of Munich (Assistant Professorship of Modeling Spatial Mobility, 2017a). The resulting scope of the MMA Study Area is shown in Figure 5.


Figure 5 The MMA Study Area

## 7.2 Inputs to SILO

Following the structure and workflow of SILO, the refinements and requirements for the land use modelling for the Northeast urban development scenarios can be summarised into the following steps:

1. Increasing the **zone system** resolution for the Northeast
2. Developing a **development timeline**
3. Creating synthetic **dwellings** for the Northeast (2011-2050)
    a. type, number of bedrooms, quality, monthly costs, restriction and quantity for each simulation year
    b. An analysis of the overall **land price** of the Study Area
4. Assignment of **employment numbers** for the base year (2011)
5. Applying an **employment forecast** for the base scenario (2011-2050)
6. Allocating proposed **scenario employment numbers** for the Northeast (2011-2050)

## 7.3 Zone System

The cities and their respective suburbs of the Study Area build up the zone system for the model. The zone system is designed so that zones in urban areas are smaller in size than zones in rural areas as shown in Figure 6. The zone system is created by the Professorship and follows the rasterization method by Moeckel and Donnelly (2015). Both Figure 6 and Figure 7 also show the investigation area of the Northeast in context of the whole Study Area.

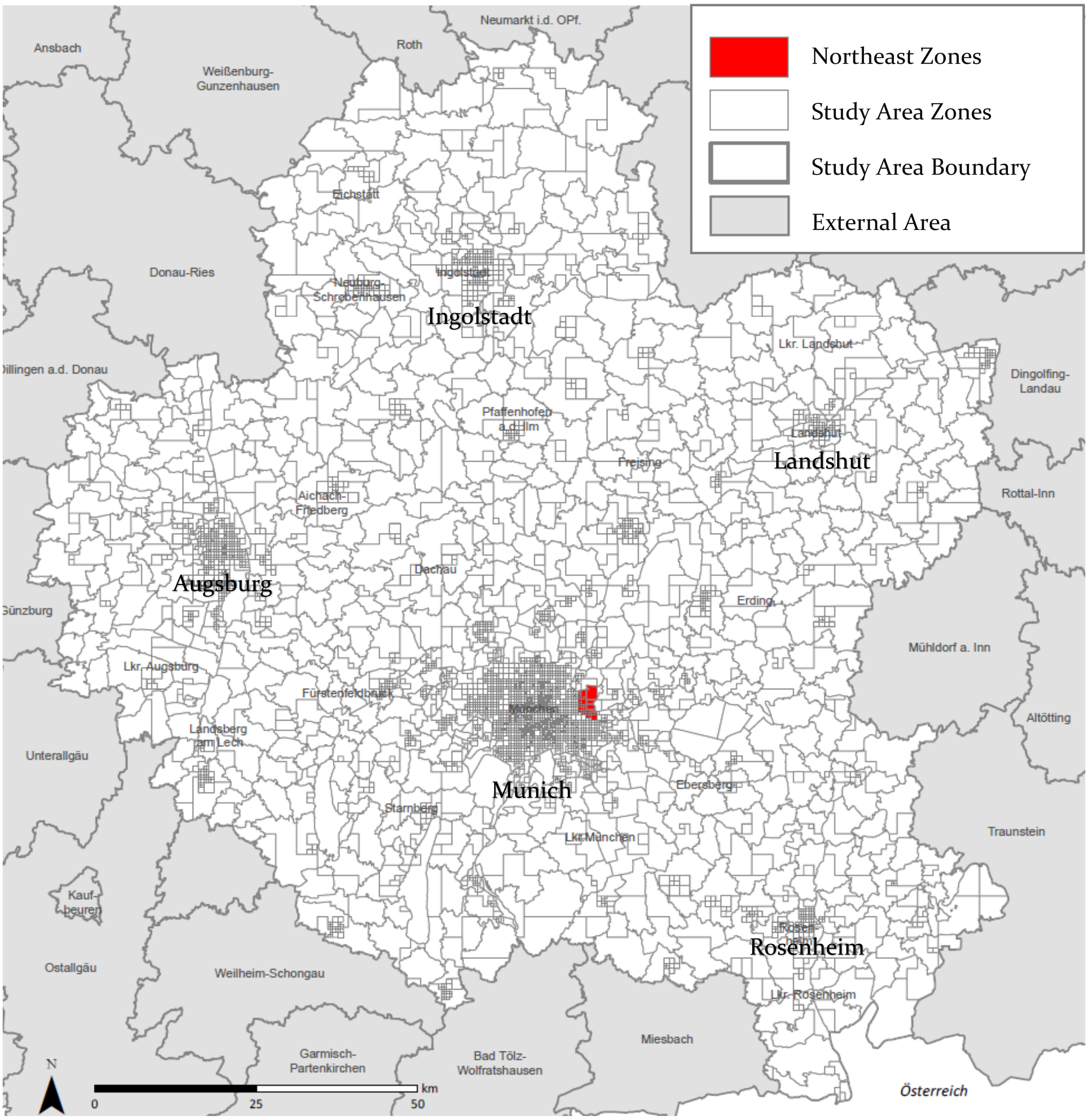


Figure 6 Zone System – MMA Study Area

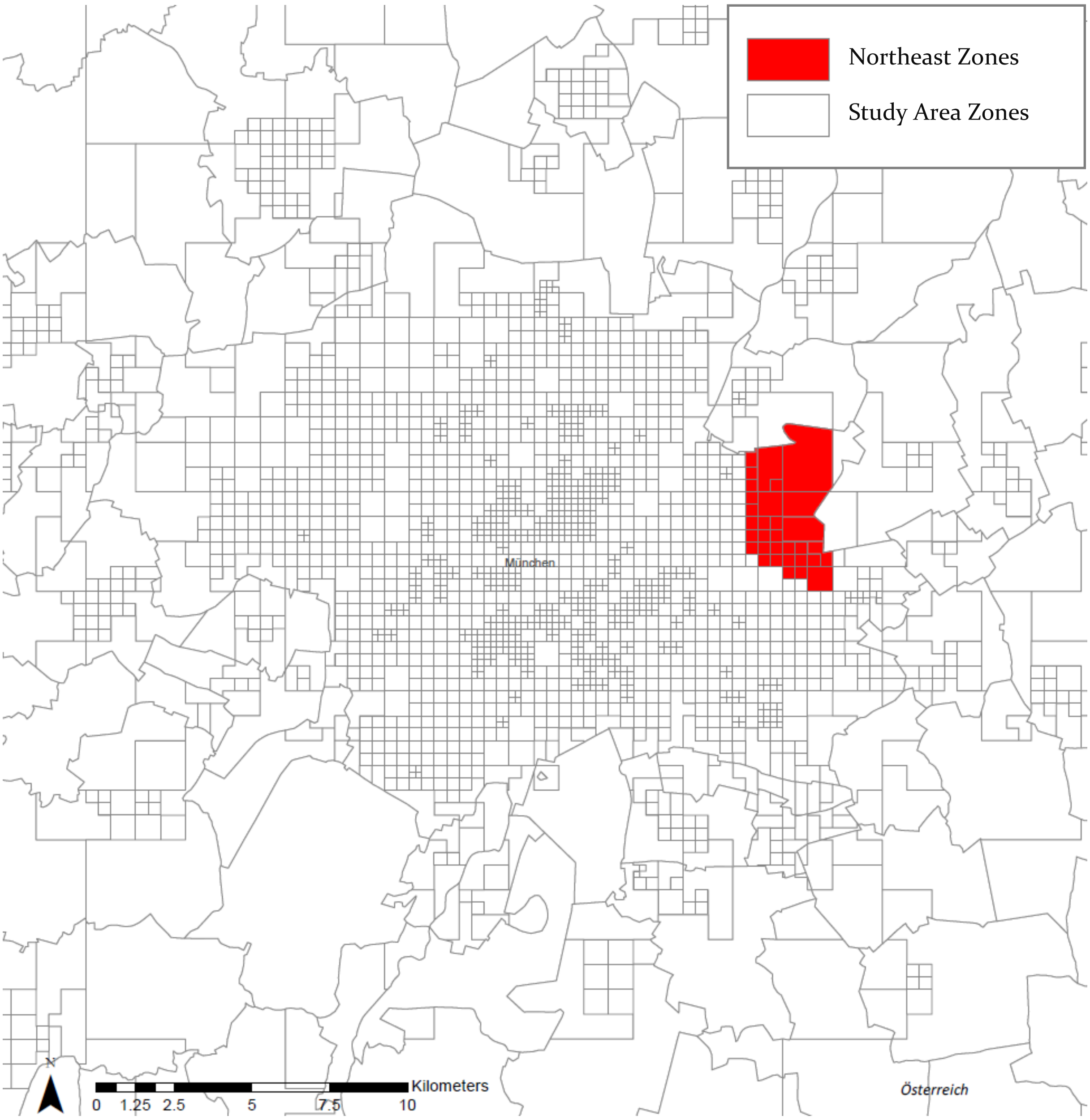



Figure 7 Zone System – Munich City and the Northeast

### 7.3.1 Increasing the Resolution in the Northeast

Defining the zone system is an essential element of the land use and transport modelling framework. The Study Area of the MMA is made up of 4,924 raster cells (zones). Due to the current low density of urbanisation in the Northeast area, the raster cells in this area are larger than those closer to the centre of Munich City. Therefore, to apply and analyse the scenarios in this area the level of resolution has been increased. The larger raster cells in the Northeast have been disaggregated into smaller raster cells, resulting in an extra 18 zones and a total of 4,942 raster cells altogether. The initial and final zone system for the Northeast is shown in Figure 8 where the disaggregation of zones is shown in red. From here onwards, the raster cells will be referred to as 'zones.'

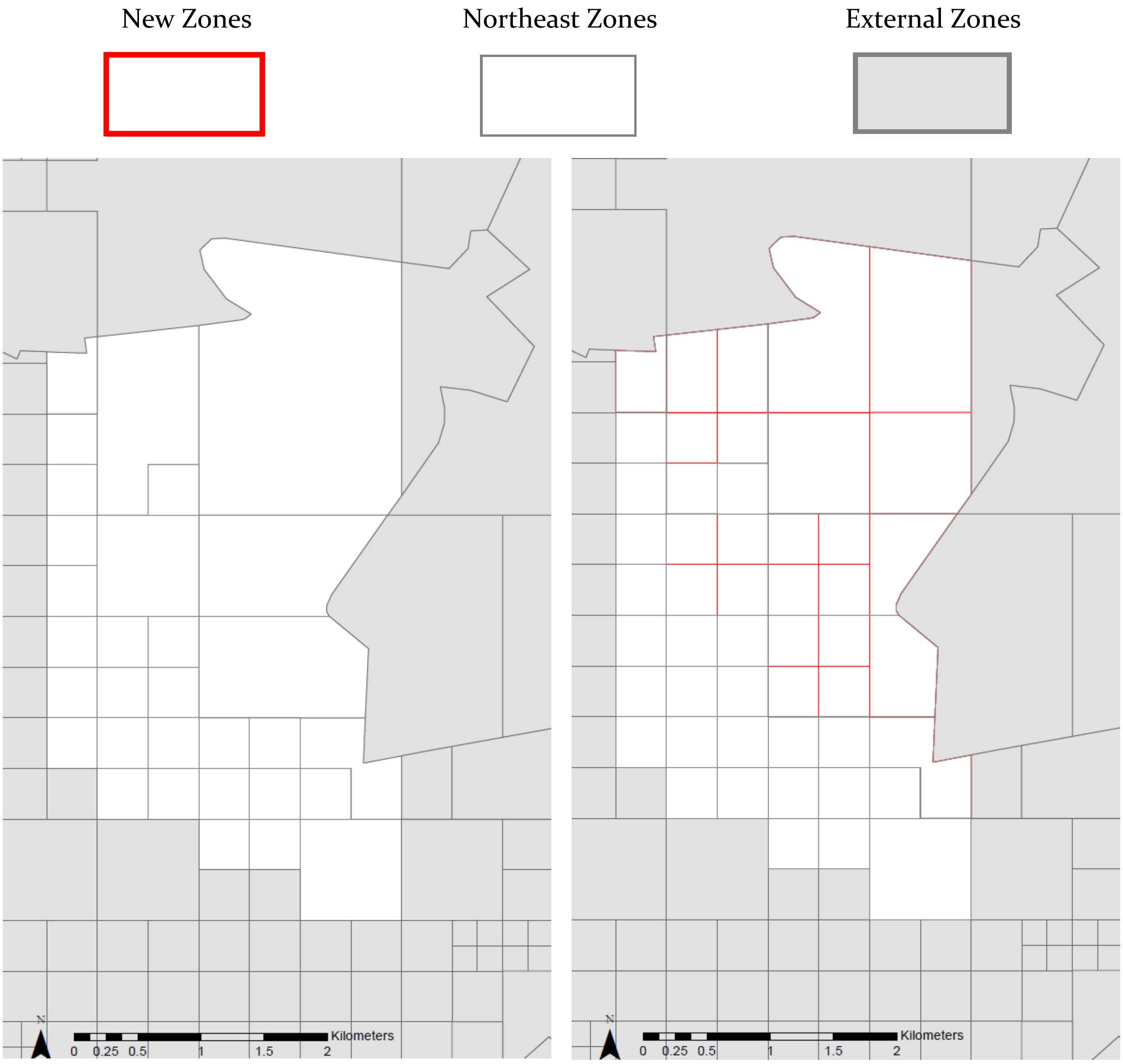



Figure 8 Zone System – Increasing the Resolution in the Northeast

## 7.4 Development Timeline

A development timeline for the Northeast is suggested by the DUPBR (Landeshauptstadt München, 2016). Each of the three scenarios undergo four phases from Phase 0 to Phase 3. DUPBR do not specify an exact year for each of the phases thus an assumption is made for the first phase to be completed in the year 2020 and then the completion of each following phase in ten year increments until the year 2050. The proposed population and employment numbers for each phase are shown for each scenario in Table 1. As introduced in Chapter 5 Northeast Munich, each scenario has slightly different population and employment targets.

Table 1 Population and Employment Development Timeline for Northeast Scenarios

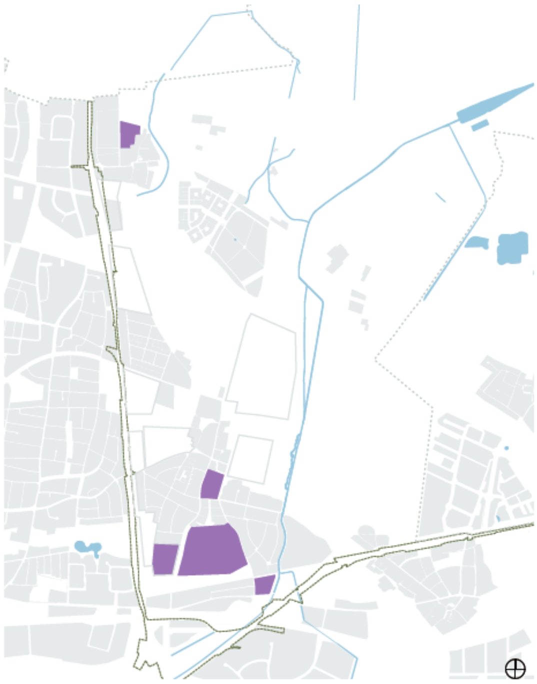
| | Scenario 1 | | Scenario 2 | | Scenario 3 | |
|---|---|---|---|---|---|---|
| | Population | No. of Jobs | Population | No. of Jobs | Population | No. of Jobs |
| **2020 Phase 0** | 3,707 | 820 | 3,642 | 677 | 3,703 | 954 |
| **2030 Phase 1** | 14,225 | 3,889 | 12,885 | 5,678 | 12,215 | 4,709 |
| **2040 Phase 2** | 7,248 | 2,171 | 8,071 | 1,682 | 9,680 | 3,810 |
| **2050 Phase 3** | 3,876 | 1,068 | 5,531 | 1,336 | 4,176 | 1,049 |
| **TOTAL** | 29,055 | 7,947 | 30,129 | 9,374 | 29,773 | 10,522 |

Geographically referenced shapefiles (geospatial vector data used in GIS software) have been provided by the DUPBR. The shapefiles include polygons of the proposed development with their expected number of people and jobs that are to be accommodated. These polygons are aligned with the zone system of the Study Area. In doing so, many of the development polygons are disaggregated to account for their intersecting zone. The population and job numbers are divided proportionally over the disaggregated polygons, according to the area.

The disaggregated polygons and their respective data entries are allocated to fit the development phasing proposed by the DUPBR. Scenario 1 phases are shown in Figure 9, Figure 10, Figure 11 and Figure 12. Scenario 2 in Figure 13, Figure 14, Figure 15 and Figure 16; And Scenario 3 in Figure 17, Figure 18, Figure 19 and Figure 20. For each figure DUPBR's plan is shown on the left and the implementation of the disaggregated development shapefiles, overlaid with the zone system is shown on the right. Finally, Table 2 provides a summary of the development timeline for all scenarios.

### 7.4.1 Scenario 1

***Phase 0***



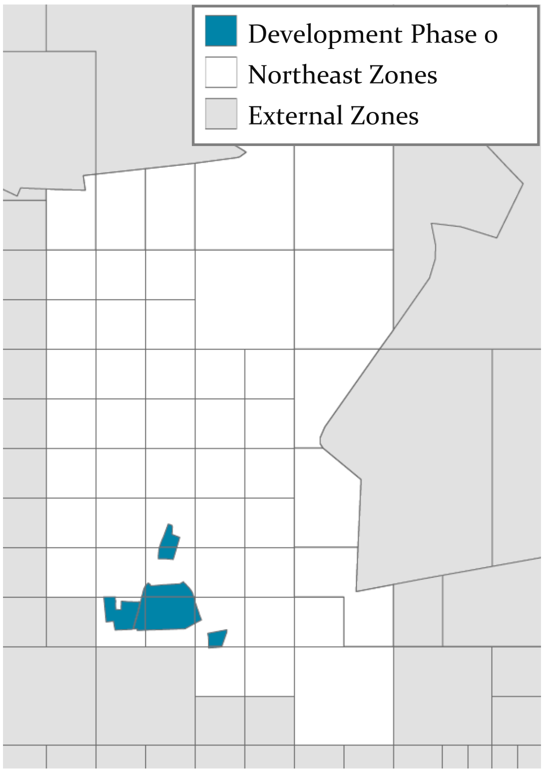
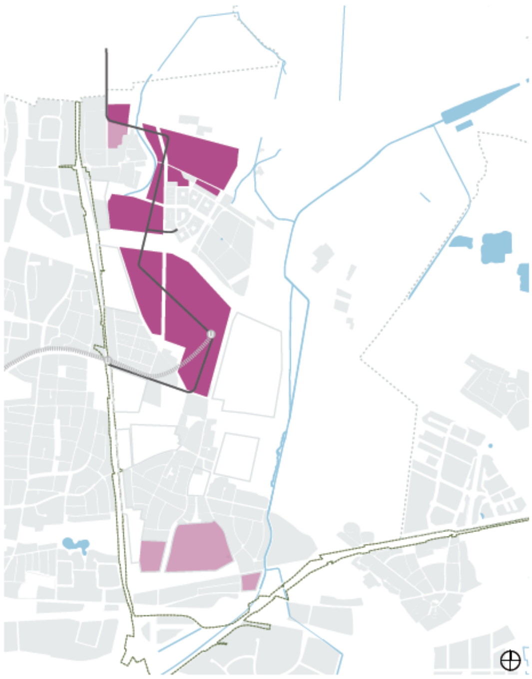



Figure 9 Scenario 1 Phase 0 (Year 2020)

***Phase 1***



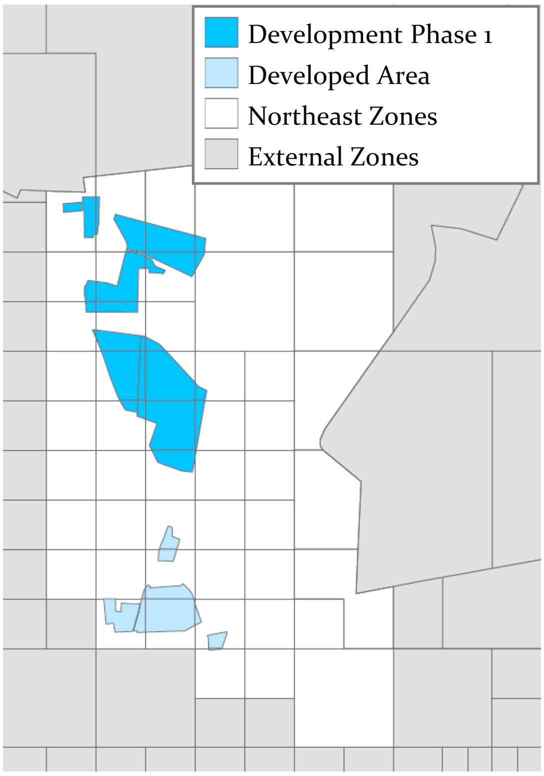
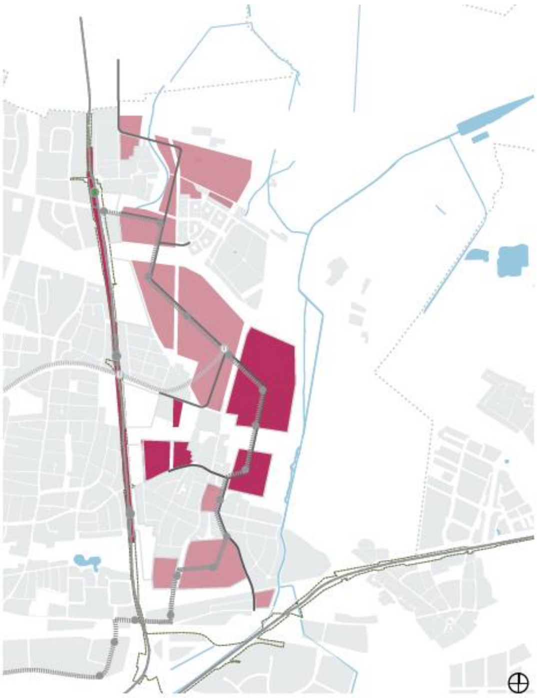



Figure 10 Scenario 1 Phase 1 (Year 2030)

***Phase 2***



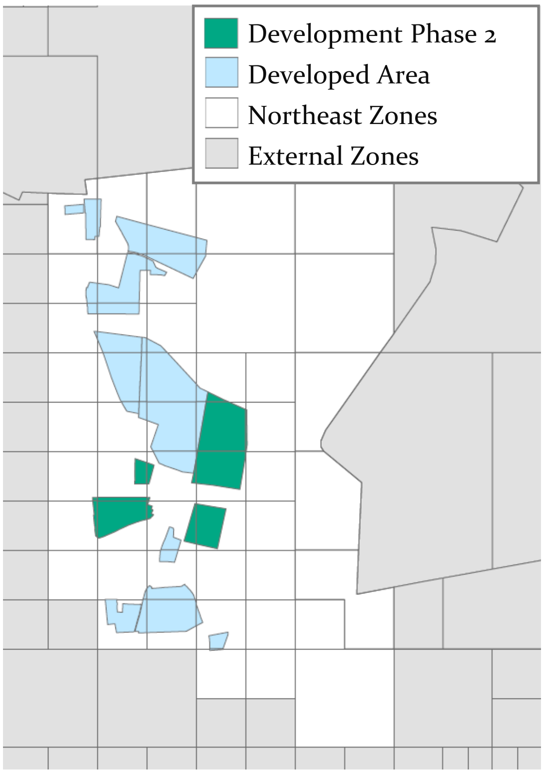
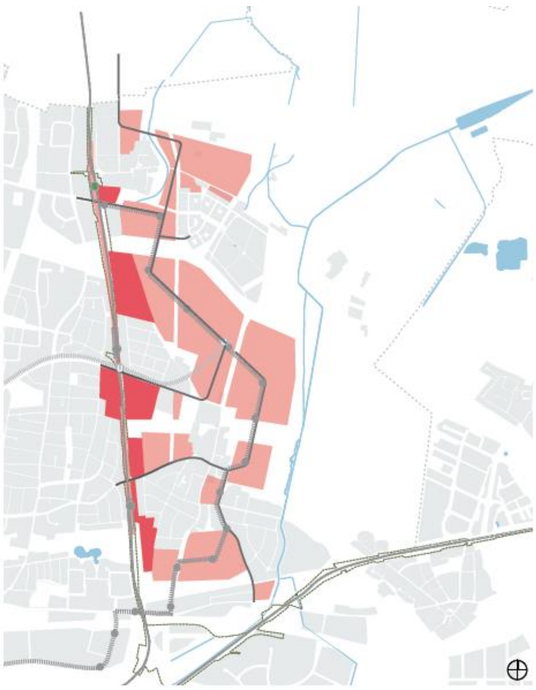



Figure 11 Scenario 1 Phase 2 (Year 2040)

***Phase 3***



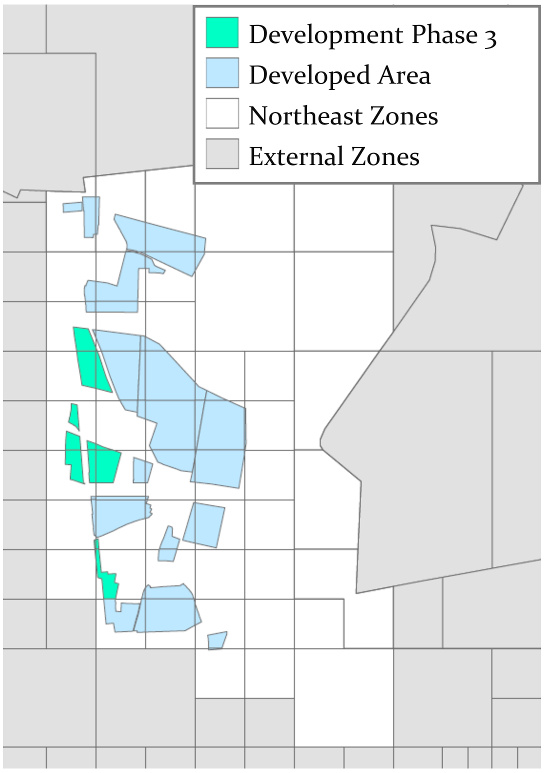



Figure 12 Scenario 1 Phase 3 (Year 2050)

### 7.4.2 Scenario 2

***Phase 0***

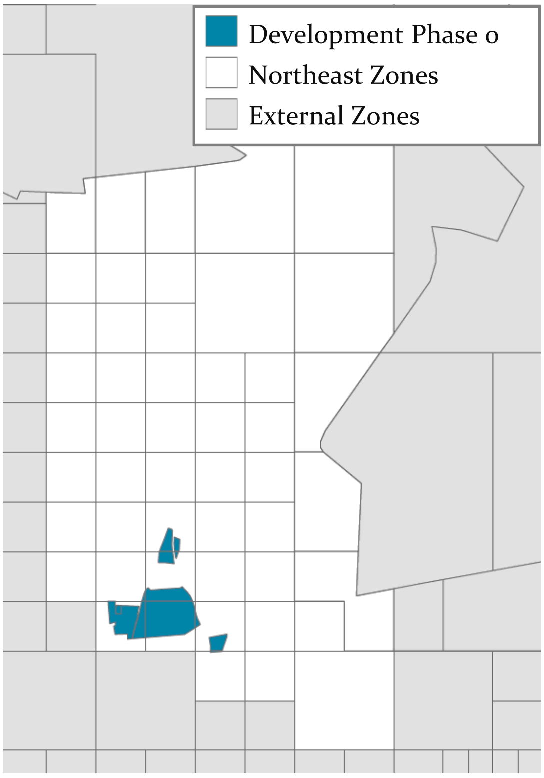
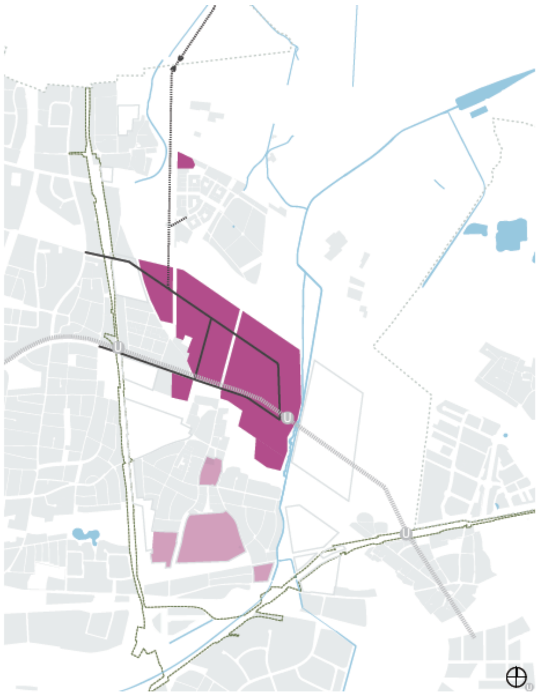



Figure 13 Scenario 2 Phase 0 (Year 2020)

***Phase 1***



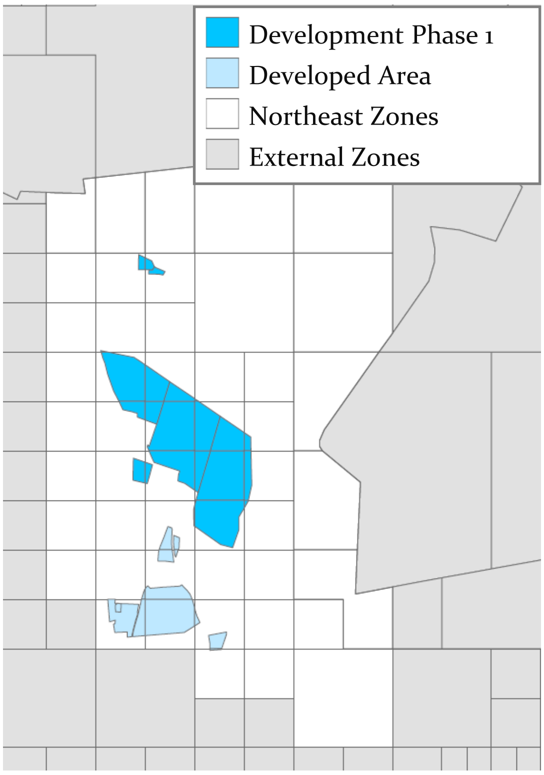



Figure 14 Scenario 2 Phase 1 (Year 2030)

***Phase 2***

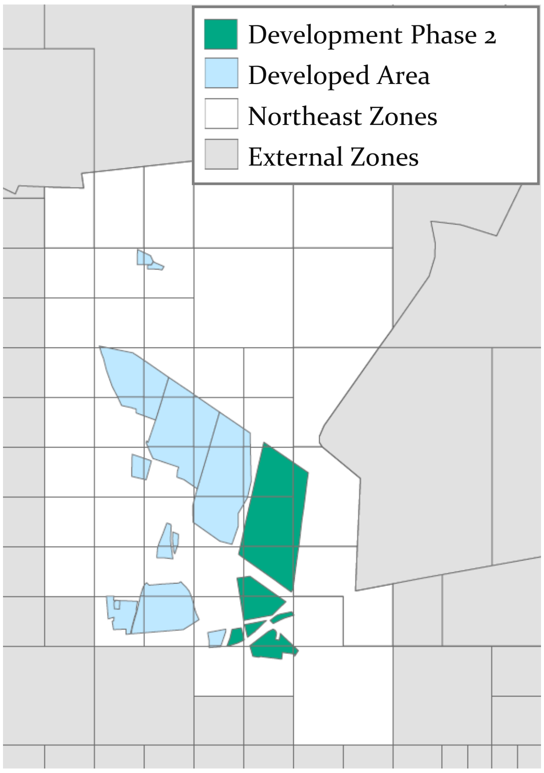



Figure 15 Scenario 2 Phase 2 (Year 2040)

***Phase 3***

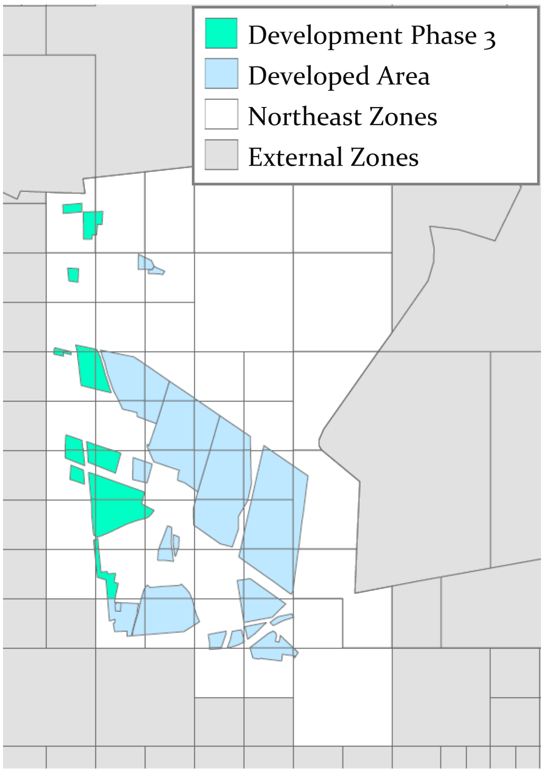



Figure 16 Scenario 2 Phase 3 (Year 2050)

### 7.4.3 Scenario 3

***Phase 0***

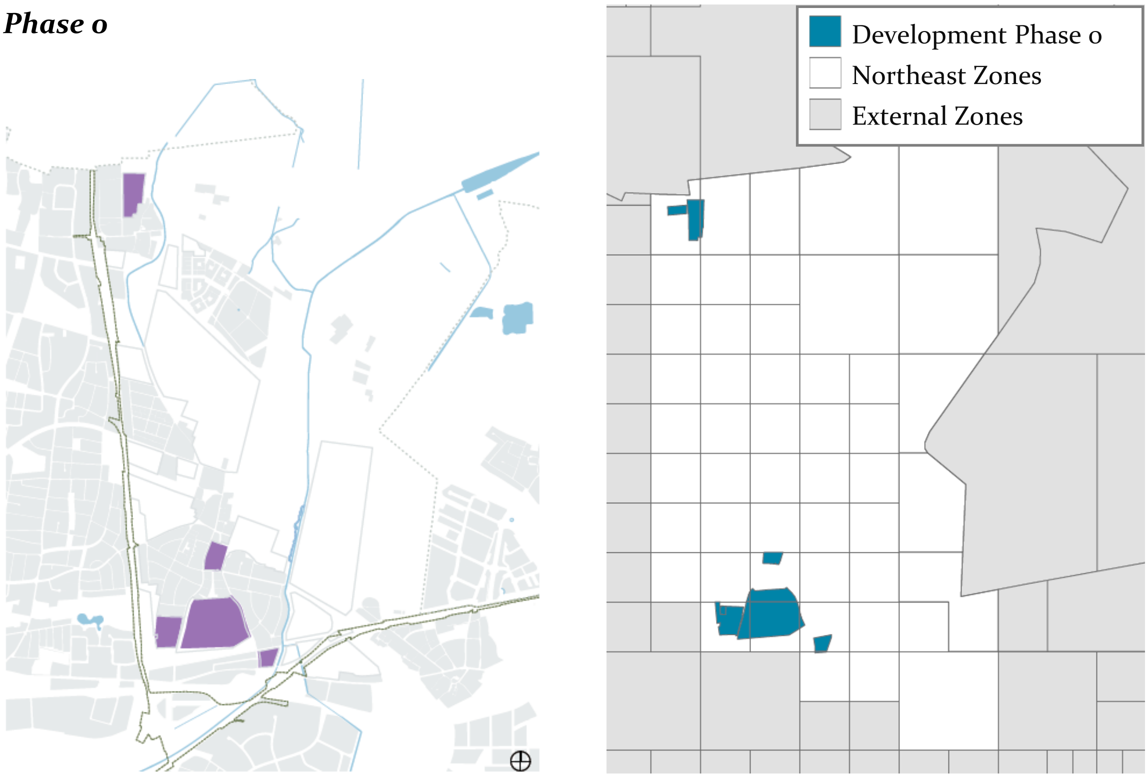



Figure 17 Scenario 3 Phase 0 (Year 2020)

***Phase 1***

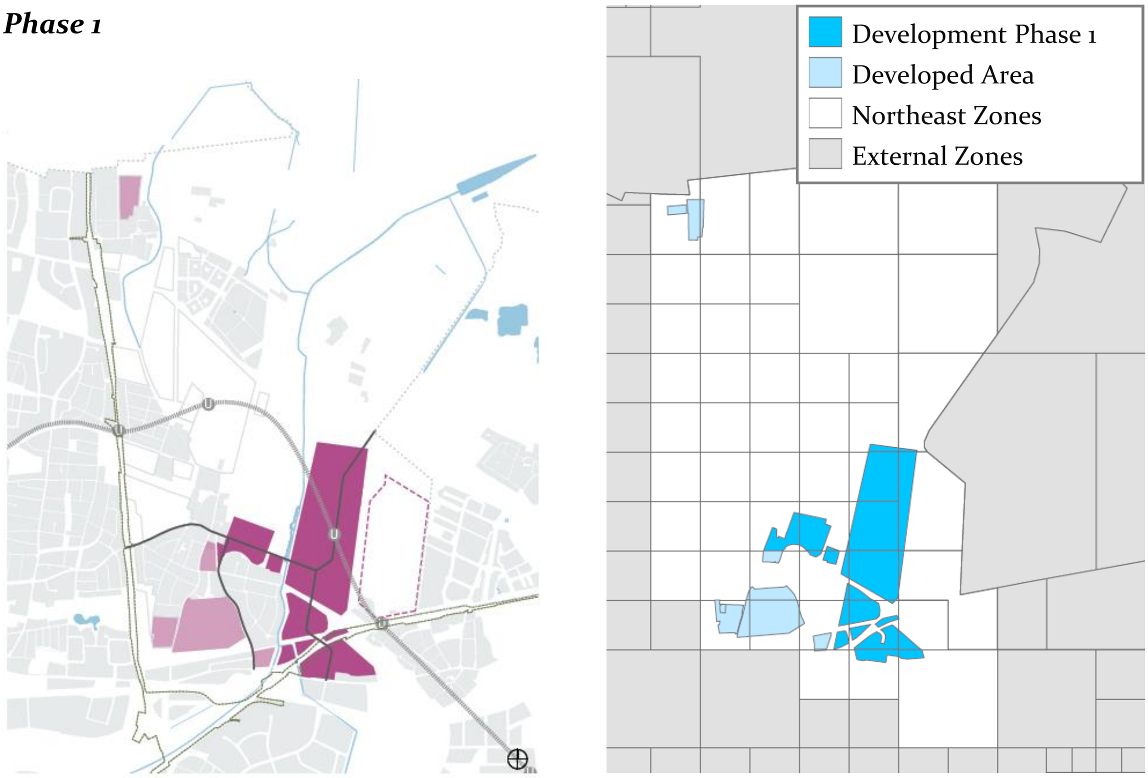
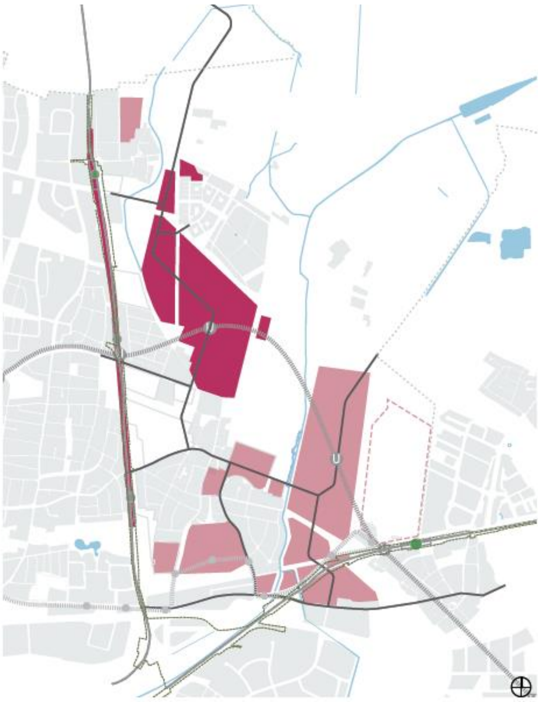



Figure 18 Scenario 3 Phase 1 (Year 2030)

### *Phase 2*



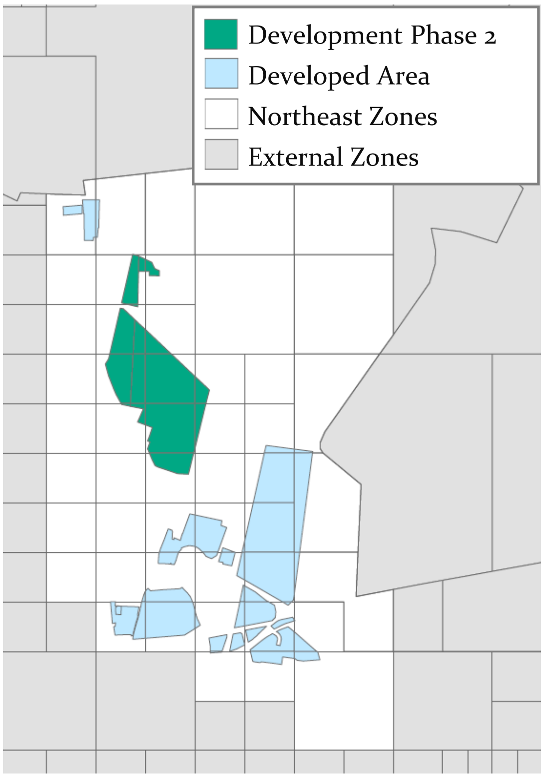
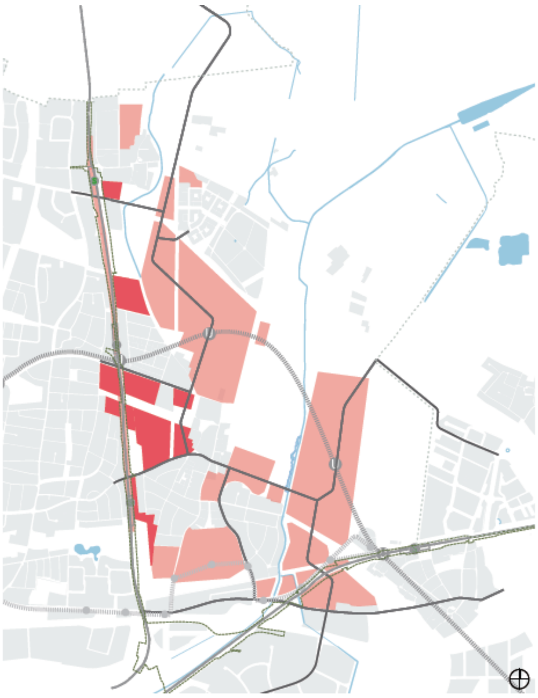



Figure 19 Scenario 3 Phase 2 (Year 2040)

### *Phase 3*



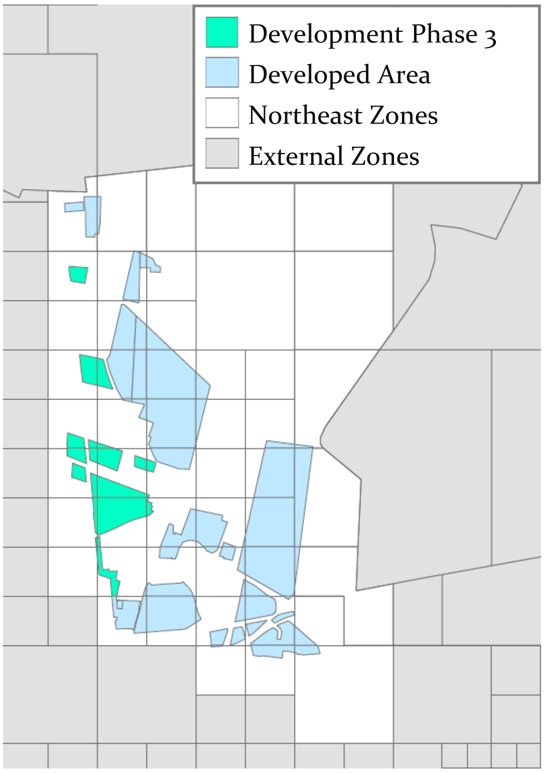
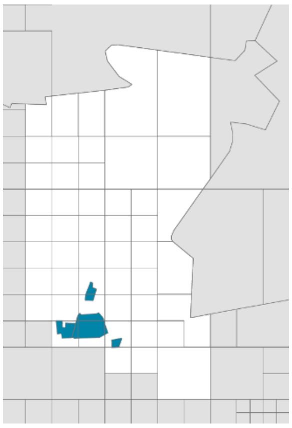
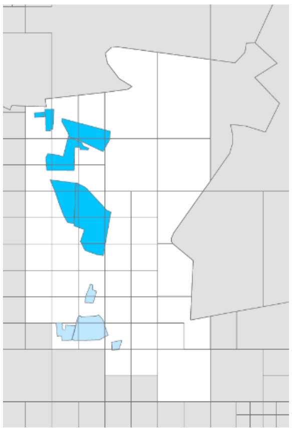
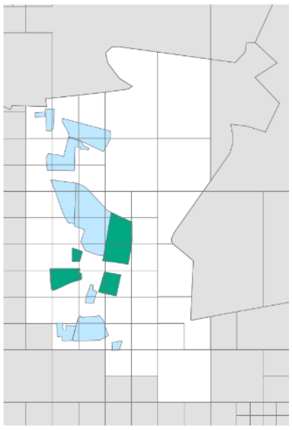
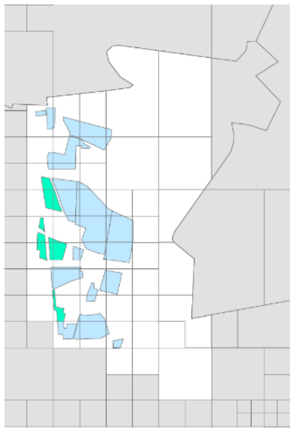
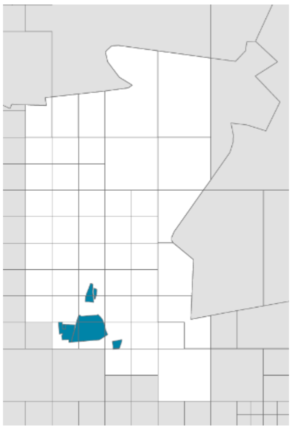
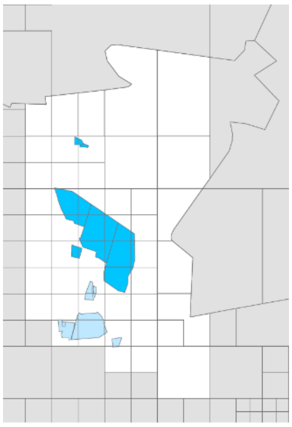
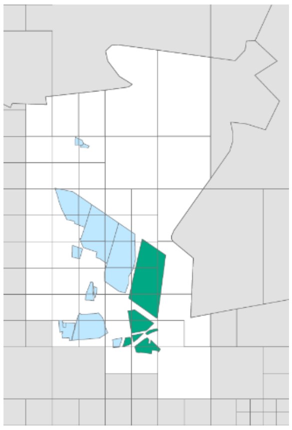
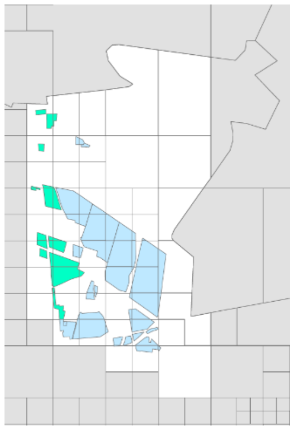
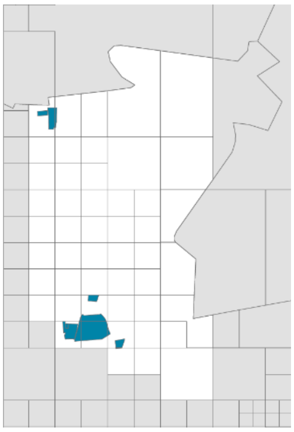
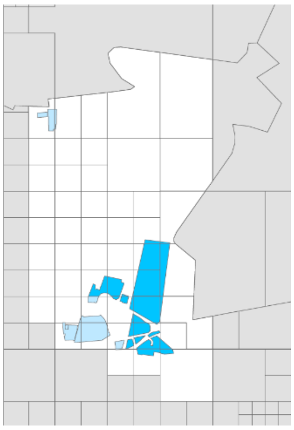
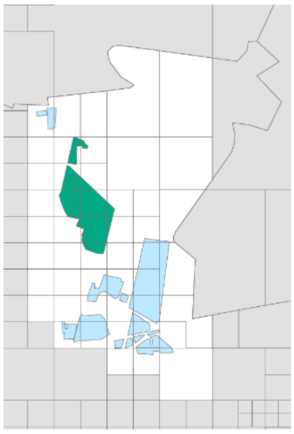
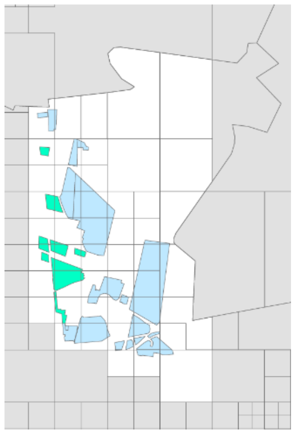



Figure 20 Scenario 3 Phase 3 (Year 2050)

Table 2 Development Timeline Summary

| Phase 0 (2020) | Phase 1 (2030) | Phase 2 (2040) | Phase 3 (2050) |
|---|---|---|---|
| **Scenario 1** | | | |
|  |  |  |  |
| **Scenario 2** | | | |
|  |  |  |  |
| **Scenario 3** | | | |
|  |  |  |  |

## 7.5 Dwellings

Each of the proposed scenarios requires an addition of newly constructed dwellings into the Northeast area. These new dwellings are added exogenously as a construction overwrite to the real estate development model. Following the development timeline, dwellings are added to the correct year, with their dwelling type, number of bedrooms, quality, monthly costs and quantity specified.

Firstly, the dwelling type for the zones are chosen to represent the land use type and density proposed by the DUPBR. The land use types and densities include 'Living Loose,' 'Living Dense,' 'Mixed Dense' and 'Work Dense.' All loose land use types assume duplexes and buildings of two to four units (MF234), and all dense land use types assume multi-family houses with five or more units (MF5+). All dwellings assume two bedrooms and the highest level of quality as would be expected of new dwellings. The monthly costs of the dwelling have been estimated using the averages of the neighbouring areas to the south: Trudering-Riem, Moosfeld and Berg Am Laim. Consequently, the monthly costs are 650 euros for those living in the dense areas (MF5+) and 800 euros for those in the loose areas (MF234). Lastly the quantity of the dwellings is calculated using DUPBR's proposed number of people living in each of the zones per scenario. Assuming each dwelling houses one household and each household has an average of 2.1 people, the quantity of dwellings for each scenario for each implementation year is shown in Table 3.

Table 3 Quantity of Additional Dwellings for Each Scenario

| | Scenario 1 | | | Scenario 2 | | | Scenario 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | MF234 | MF5+ | Total | MF234 | MF5+ | Total | MF234 | MF5+ | Total |
| **2020** | 1640 | 125 | 1765 | 1625 | 110 | 1735 | 1409 | 355 | 1764 |
| **2030** | 2576 | 4198 | 6774 | 181 | 5955 | 6136 | 695 | 5122 | 5817 |
| **2040** | 1334 | 2117 | 3451 | 3230 | 614 | 3844 | 305 | 4305 | 4610 |
| **2050** | 225 | 1620 | 1845 | 992 | 595 | 1587 | 1441 | 0 | 1441 |
| **Total** | 5775 | 8060 | 13835 | 6028 | 7274 | 13302 | 3850 | 9782 | 13632 |

### 7.5.1 Land Price

All other dwellings, excluding those exogenously added with the scenario analyses, use the land price to determine the monthly costs for rent. A refinement of these land prices for the MMA Study Area has been completed prior to simulation.

Land price information from the *Gutachterausschuss für Grundstückswerte* 'Expert Committee for Land Values' (2015) for the municipality of Munich is applied. This data is in the form of 71 maps showing the buildings in the central Munich area covered by a coarser polygon that groups buildings with the same land price and land use. Following the land price/use polygons a simple methodology is used to allocate land price values to the raster cells. Using GIS, the maps (in the form of pdfs) are aligned and an approximate centroid is formed for each polygon. Completed manually, the land price in euros per metre square and the land use are digitised for each centroid. Once completed, the data points for the municipality of Munich (1,853 points) were combined with those from other municipalities that also has land price data. This was prepared with the Professorship and together the data points (5,586 in total) are used to estimate a land price value for all zones in the MMA Study Area.

Naturally not all areas thus not all zones in the MMA has a land use data point. Zones with data points are assigned an average value of the data points. Zones without data points use an average value of all the zones that has a similar area. This assumes that, due to the nature of the initial rasterization method to form the zone system, the smaller the zone the more densely developed the area is, hence a similar land price.

## 7.6 Employment

Employment in the form of jobs are one of the main data containers formed alongside the synthetic population. An estimate of job numbers has been completed by the Professorship for the synthetic population using aggregate employment data. The following sections describe how this initial estimate has been refined. A methodology to forecast future number of jobs is described and the inclusion of new jobs with the development scenarios is shown.

### 7.6.1 Employment Estimate

Firstly, the initial estimate was based on the dataset where aggregated employment numbers were available for all *Landkreis* 'County' and for all *Gemeinde* 'Municipality' of over 10,000 people. The Study Area is made up of 28 Landkreis and 446 Gemeinde of which 83 consists of over 10,000 people. It was found that out of the initial 4,924 zones, 3,976 are within the Gemeinde of over 10,000 people (and hence have aggregated employment data at the Gemeinde level) and 948 zones are within Gemeinde of less than 10,000 people. For those zones that are within a Gemeinde of over 10,000 people, an area weighted proportion was used to estimate employment numbers for each zone. However, for those zones that are not within a Gemeinde of over 10,000 people, the employment numbers at the Landkreis level had to be applied proportionally.

The aggregated employment numbers that are available for the Landkreis and the Gemeinde are divided into the ten main job types defined in the *Statistisches Bundesamt* 'Federal Office of Statistics' (Statistisches Bundesamt, 2008). Thus, each zone of the Study Area has an estimated number of jobs for each of the ten job types, which are the following:

1. Agriculture, forestry and fisheries
2. Mining and manufacturing industries
3. Power supply, water supply and waste disposal
4. Construction industry

5. Trade, vehicle repairs, hospitality (including restaurants/cafes/bars/etc.)
6. Transport and storage, and communication
7. Financial services and insurance
8. Real estate and development services
9. Public administration
10. Public and private services

Due to the coarseness of the initial employment estimate a more detailed approach is used to attain employment numbers across the zones for each of the job types. For the purposes of a more detailed representation of the number of jobs per type in each zone, spatial information from Geofabrik is used (Geofabrik, 2016). The information from Geofrabrik is essentially extracted OpenStreetMap (OSM) data for selected regions. The geographically referenced shapefiles for the whole of Bayern has been downloaded and used for the analysis.

The specific groups of data used from the downloaded shapefiles include the Points of Interests (POI) as polygons, POIs as points, building polygons and land use polygons. The goal was to assign employment related polygons and points to each of the zones of the Study Area. Firstly, a filtering of the records was completed.

The MMA Study Area has 47,784 POI polygons categorised into 135 different types of OSM tags. After a filtering process to remove non-employment related categories, 22,527 of the 47,784 POI polygons, were used. Similarly, there are 75,095 POI points categorised into the same 135 OSM tags. 34,067 of 75,095 POI points are used after filtering. Likewise, there are 677,675 building polygons of which 401,699 have no OSM tag and the remaining 275,976 polygons are categorised into 166 different types of OSM tags. Building polygons with no tag have been categorised using the tag of the land use polygon the building polygon is found within. After filtering out non-employment related tags, 592,696 of 677,675 building polygons are used. Lastly, 48,462 of 151,752 land use polygons are used and are categorised into 19 different land use types. A list of the OSM tags, the number of entities in each and their assigned job type classification number (null for neglected tags) can be found in Section C.2 of Appendix C.

Before summing up the polygon areas to their appropriate zones, a percentage distribution of areas has been applied for each building polygon according to their assigned job type. For example, a building tagged ‘industrial’ falls into the Manufacturing job type. For all buildings assigned the ‘Manufacturing’ job type 55% of the area is assigned to manufacturing, 0% to agriculture, 2% to utility, 8% to construction, 3% to retail, 7% to transportation, 0% to finance, 8% to real estate, 1% to admin and 16% to service. These percentages are based on the top fifty records of the initial employment estimate for each job type; and thus, have different distributing proportions for each job type. The distribution percentages for each job type applied to the building areas can be found in Section C.2 of Appendix C.

Afterwards, a hierarchical system removed overlapping pieces of entities as POI polygons also exist as building polygons and at times POI points coexist with the POI polygon. Furthermore, not all building polygons contain a building type classification tag therefore the land use polygon containing the building polygon is applied to the building polygon. Hence, the POI polygons are the most dominant, followed by both the building polygons and the POI points. Building polygons and POI points may exist in the same spatial location.

An example of this hierarchy system is shown in Figure 21. The figure shows the different polygons, points and the zone boundaries in the northern part of the TUM city campus. For each zone, the hierarchical system will firstly assign the areas of POI polygon areas as the most dominant (the building polygons below the POI polygon has been removed), then the areas of the building polygons that have an appropriate tag. POI points that are within POI polygons are neglected however those that are not are accounted for. To give an area value to POI points, an average area from the known POI polygons (with the same OSM tag) are assigned.

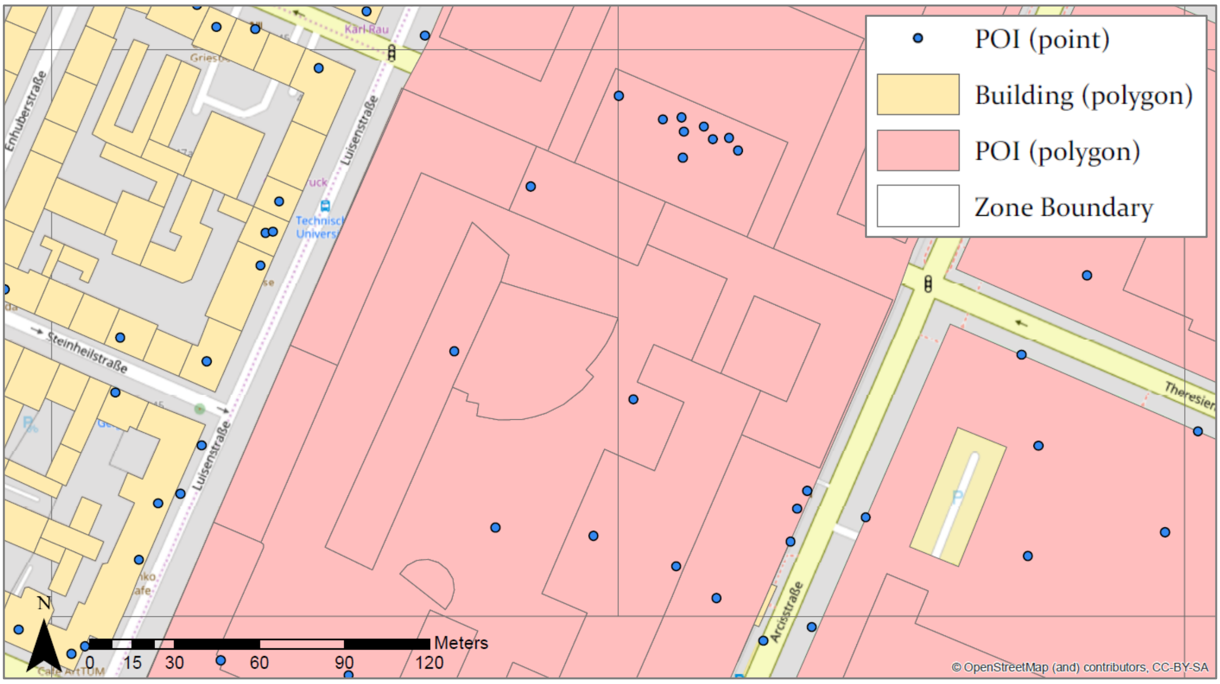



Figure 21 OSM Point and Polygon Hierarchical System Used for Estimating Employment (Created using data from openstreetmap.org, 2017)

Finally, a matrix with each of the zones by the ten job types (in square metres) were produced. With the zone by job type matrix, the proportions calculated initially using the total number of jobs by job type and municipality (of over 10,000 people) is applied to transform the jobs in areas to jobs in numbers.

### 7.6.2 Employment Forecast

Employment forecasts are made for the MMA Study Area for the years 2011-2050 using the numbers from the *Erwerbstätigenprognose für die Landeshauptstadt München und die Planungsregion 14,* 'Employment forecast for the state capital Munich and the planning region 14' report (empirica, 2015). The report was prepared for the *Referat für Arbeit und Wirtschaft,* 'Department of Labour and Economic Affairs' and the DUPBR.

Forecasts for the Munich Region (Munich City, Dachau, Ebersberg, Erding/Freising, Fürstenfeldbruck, Landsberg, Munich County and Starnberg) exist until the year 2030. Forecasts for the Munich Region has been used for this thesis. For the remaining years, with no employment forecast between 2030 and 2050, an interpolation has been made.

Furthermore, empirica (2015) suggests three employment forecast scenarios, a negative scenario, a more conservative basis scenario and the trend scenario which reflects the real growth in employment during the previous 13 years between 2000 and 2013 in Munich. Therefore, for the application of these numbers into the Northeast study, the trend forecast has been used for the initial years (2011-2030) and the basis forecast for the final twenty years (2030-2050). The percentage change in the number of jobs for each of the 10 job types per year are shown in Table 4.

Table 4 Study Area Employment Forecast by Job Type for Years 2011-2050

| | Job Type | Years 2011-2030 Trend (% change per year) | Years 2030-2050 Basis (% change per year) |
|---|---|---|---|
| **job1** | Agriculture | -1.64% | -2.27% |
| **job2** | Manufacturing | -0.37% | 0.56% |
| **job3** | Utility | -0.37% | 0.56% |
| **job4** | Construction | 0.82% | 1.02% |
| **job5** | Retail | 0.98% | 0.39% |
| **job6** | Transportation | 0.98% | 0.39% |
| **job7** | Finance | 1.83% | 0.26% |
| **job8** | Real Estate | 1.83% | 0.26% |
| **job9** | Administration | 0.86% | 0.80% |
| **job10** | Service | 0.86% | 0.80% |

The trend employment forecast suggests a decrease in agriculture, manufacturing and utility jobs, whereas construction, retail, transportation, finance, real estate, administration and service jobs are expected to increase from year to year. Alternatively, the basis employment forecast suggests an increase for both manufacturing and utility jobs with only agricultural jobs decreasing each year. In both cases, agricultural jobs are expected to decrease from year to year.

### 7.6.3 Employment Scenarios

On top of the underlying employment changes, new jobs with the development scenarios are added to the model exogenously. The number of jobs targeted for each scenario are provided by the DUPBR. An estimate of the type of jobs introduced to the scenarios are made using the areas of Neuaubing, Pasing and the recently developed area of Freiham. The job type proportions of these areas are shown in Table 5.

Table 5 Job Type Proportions Used for Northeast Analysis (%)

| Job Type | job1 | job2 | job3 | job4 | job5 | job6 | job7 | job8 | job9 | job10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Proportion** | 0.1 | 6.0 | 0.6 | 1.8 | 21.2 | 8.7 | 6.2 | 20.8 | 7.5 | 27.0 |

Public and private service jobs (job type 10) will make up over a quarter of the jobs in the Northeast followed by retail (job type 5) and then real estate and development services (job type 8). Agricultural jobs, industrial jobs and construction jobs (job types 1, 3 and 4) have the least proportion of all jobs. The job percentages are then applied to the total number of jobs proposed for each phase of each scenario. The final number of jobs added exogenously with the distribution is shown in Table 6, Table 7 and Table 8 for scenarios one, two and three, respectively.

Table 6 Number of Jobs with the Northeast Development by Job Type per Phase – Scenario 1

| Phase | Employment | job1 | job2 | job3 | job4 | job5 | job6 | job7 | job8 | job9 | job10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 820 | 1 | 49 | 5 | 15 | 174 | 71 | 51 | 171 | 61 | 222 |
| **1** | 3889 | 5 | 232 | 25 | 71 | 825 | 337 | 241 | 810 | 291 | 1051 |
| **2** | 2171 | 3 | 129 | 14 | 40 | 460 | 188 | 135 | 452 | 162 | 587 |
| **3** | 1068 | 2 | 64 | 7 | 20 | 226 | 93 | 66 | 222 | 80 | 289 |
| **TOTAL** | 7947 | 11 | 474 | 50 | 146 | 1686 | 689 | 493 | 1655 | 595 | 2148 |

Table 7 Number of Jobs with the Northeast Development by Job Type per Phase – Scenario 2

| Phase | Employment | job1 | job2 | job3 | job4 | job5 | job6 | job7 | job8 | job9 | job10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 677 | 1 | 40 | 4 | 12 | 144 | 59 | 42 | 141 | 51 | 183 |
| **1** | 5678 | 8 | 339 | 36 | 104 | 1204 | 492 | 352 | 1183 | 425 | 1535 |
| **2** | 1682 | 2 | 100 | 11 | 31 | 357 | 146 | 104 | 350 | 126 | 455 |
| **3** | 1336 | 2 | 80 | 8 | 25 | 283 | 116 | 83 | 278 | 100 | 361 |
| **TOTAL** | 9374 | 13 | 559 | 59 | 172 | 1988 | 813 | 582 | 1952 | 702 | 2534 |

Table 8 Number of Jobs with the Northeast Development by Job Type per Phase – Scenario 3

| Phase | Employment | job1 | job2 | job3 | job4 | job5 | job6 | job7 | job8 | job9 | job10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0** | 954 | 1 | 57 | 6 | 18 | 202 | 83 | 59 | 199 | 71 | 258 |
| **1** | 4709 | 7 | 281 | 30 | 87 | 999 | 408 | 292 | 981 | 352 | 1273 |
| **2** | 3810 | 5 | 227 | 24 | 70 | 808 | 330 | 236 | 794 | 285 | 1030 |
| **3** | 1049 | 1 | 63 | 7 | 19 | 222 | 91 | 65 | 218 | 79 | 284 |
| **TOTAL** | 10522 | 15 | 627 | 66 | 193 | 2232 | 912 | 653 | 2192 | 787 | 2844 |

# 8 Transport Model

## 8.1 Inputs to MATSim

The inputs considered for MATSim are the private transport network and the public transport network for the MMA. Prior to the addition of the proposed new infrastructure, the plan has been cross-checked with the Transport Development Plan (VEP) of Munich (Landeshauptstadt München, 2006) for consistency. Both the *Münchner Verkehrsgesellschaft* 'Munich Transport Company' (MVG) and *Münchner Verkehrs-/Tarifverbund* 'Munich Transport and Tariff Association' (MVV) include the possible additions of proposed transport infrastructure.

The new networks for each scenario are included into the existing MATSim transport network of MMA. MMA's overall private transport network is shown in Figure 22, a closer view of central Munich in Figure 23 and the Northeast area in Figure 24.

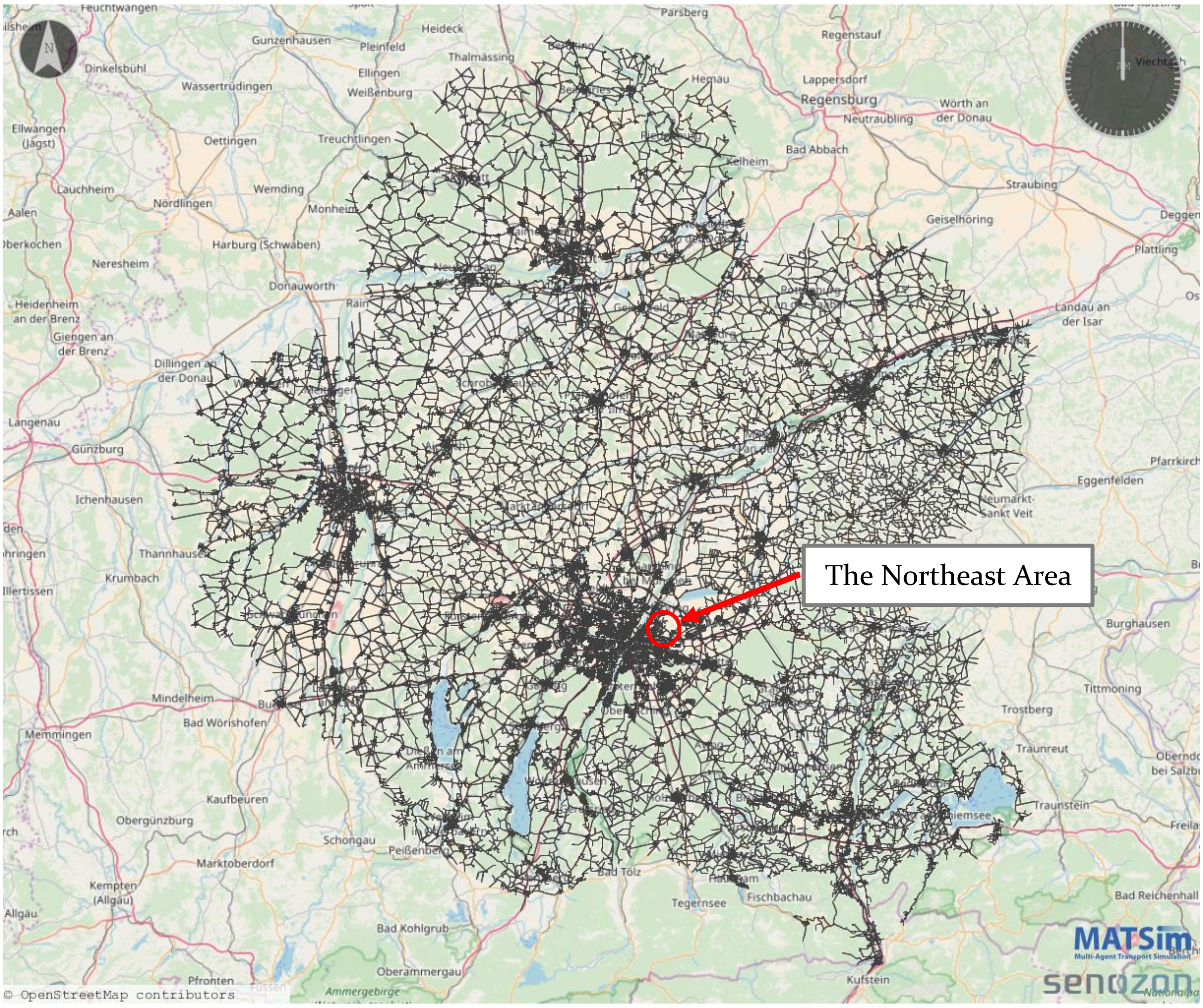



Figure 22 MATSim Private Transport Network of MMA

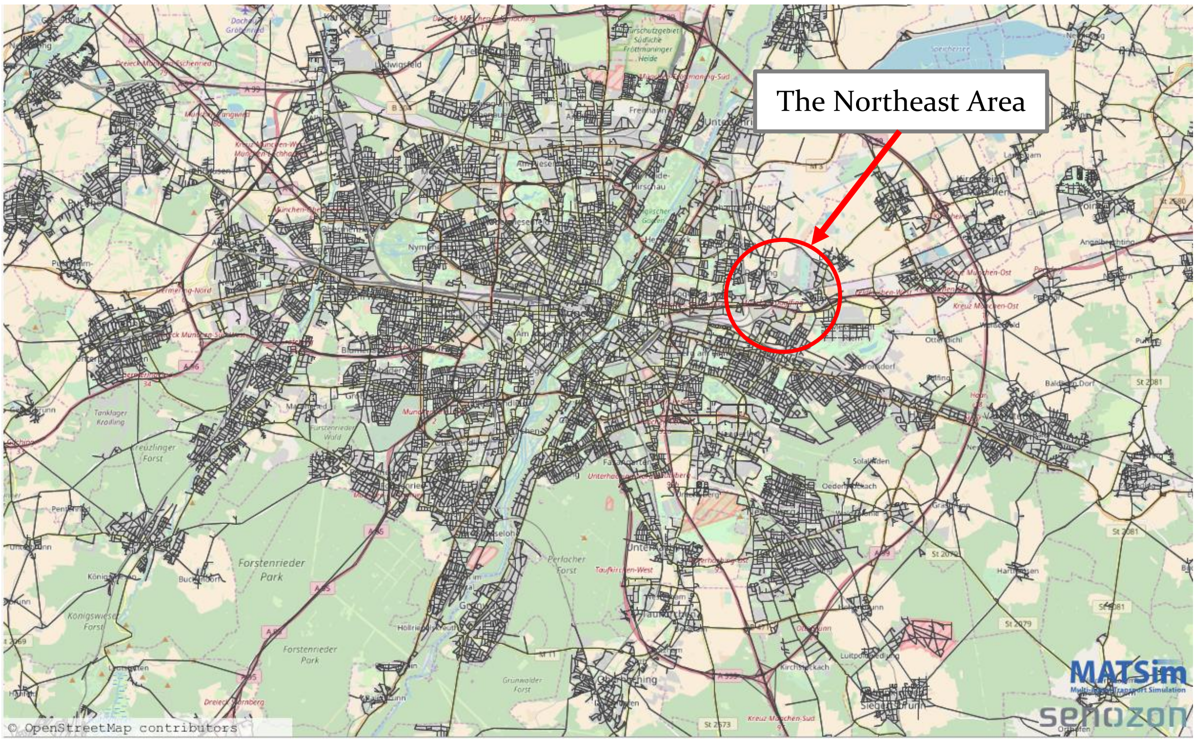



Figure 23 MATSim Private Transport Network of Munich City

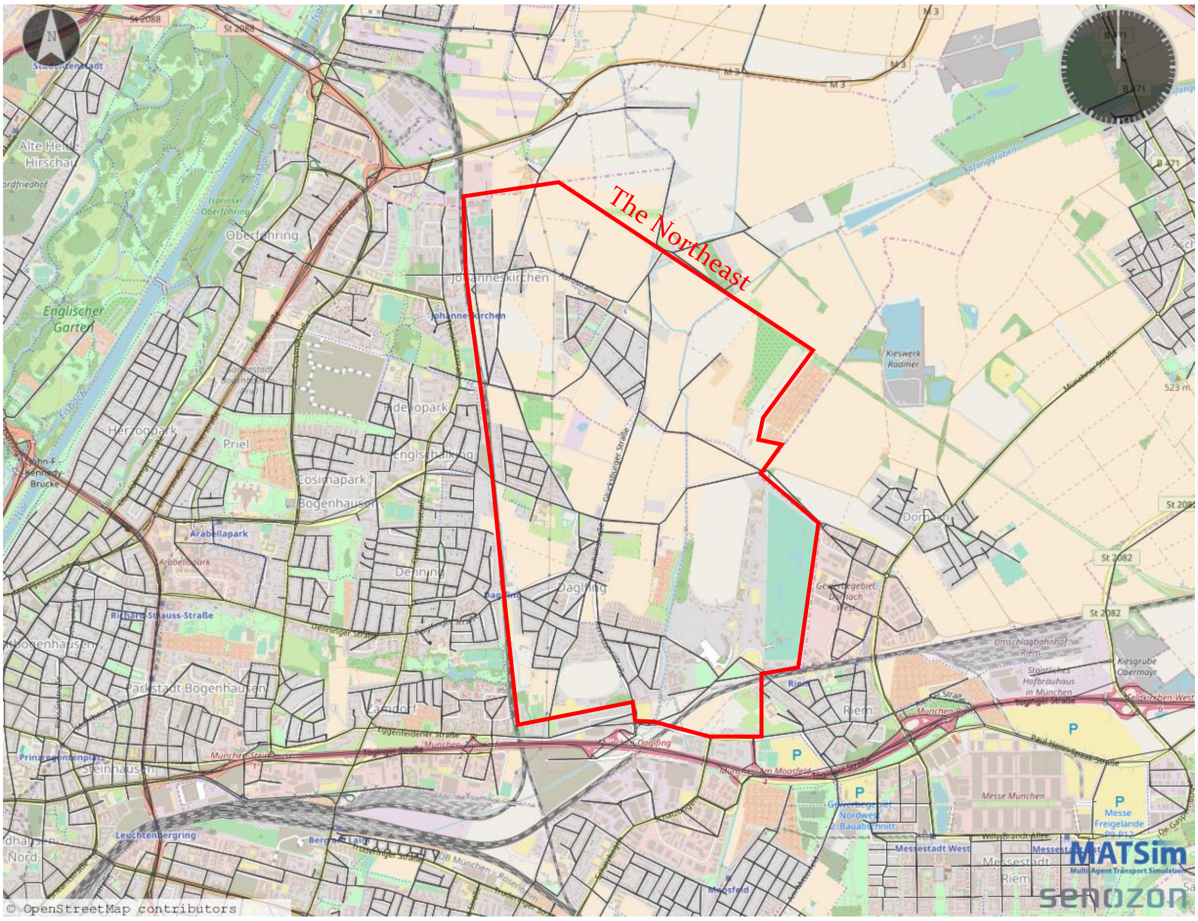



Figure 24 MATSim Private Transport Network of the Northeast

## 8.2 Private Transport Network

The proposed roads for each scenario is included into the MMA transport network by an allocation of new nodes and links with their respective characteristics. All new roads with the development scenarios have the following characteristics: a residential road type, free speed of 22 kilometres per hour, a capacity of 600 vehicles per lane per direction, and allowable modes including cars only. The proposed private transport network is described for each scenario.

***Scenario 1***

The private transport network for Scenario 1 focuses on the flow in the north-south axis. The axis creates an extension from the Rennbahnstraße / Riemerstraße intersection (Töginger Straße Autobahn) from the south and connects to the M3 highway to the north. The new links included into the existing private transport are shown in red in Figure 25.

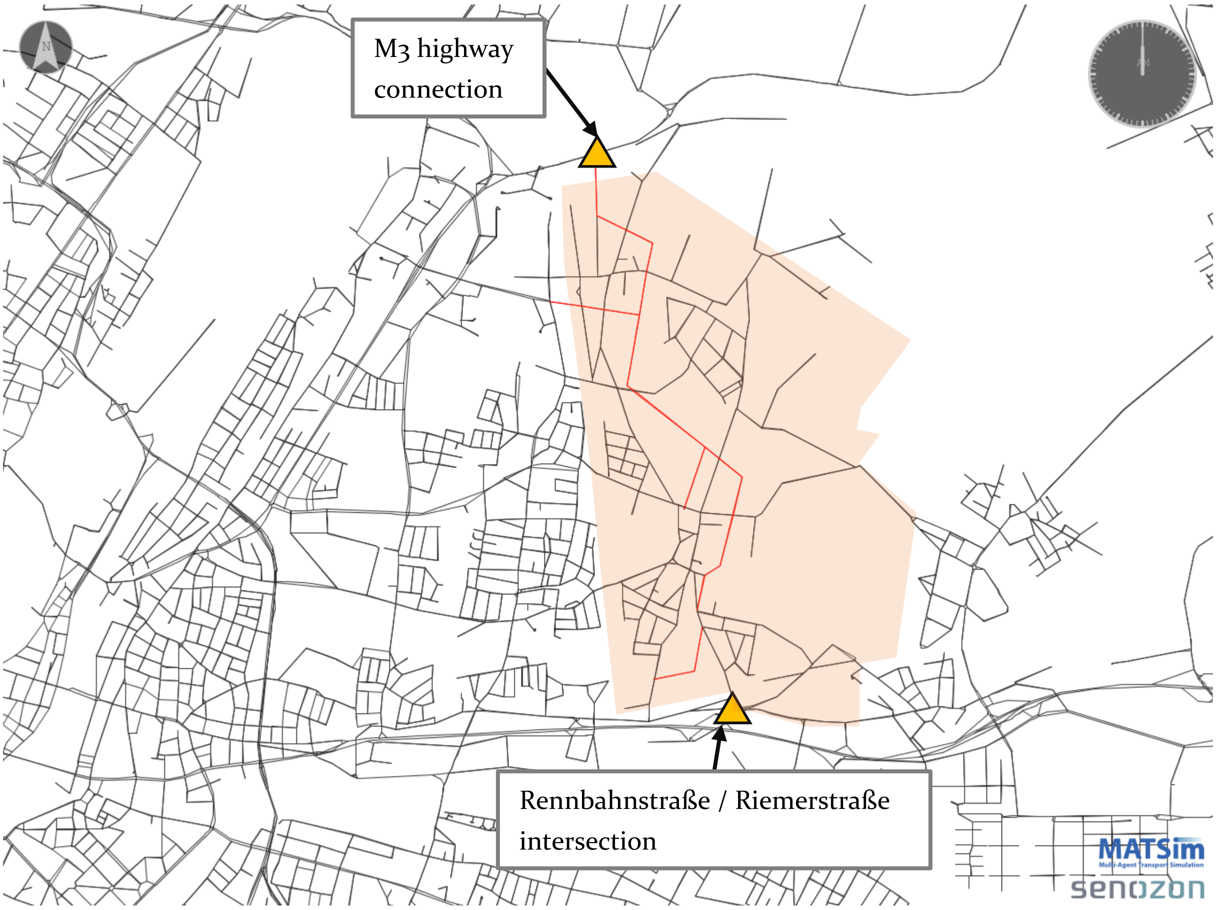



Figure 25 MATSim Private Transport Network of the Northeast – Scenario 1

### *Scenario 2*

Like Scenario 1, the private transport network for Scenario 2 also focuses on the north-south connection. The area is linked to the M3 highway in the north and the Töginger Straße Autobahn to the south. There are slight differences in the internal road network as they follow the settlement structure of each scenario. The new links included into the existing private transport are shown in red in Figure 26.


Figure 26 MATSim Private Transport Network of the Northeast – Scenario 2

### *Scenario 3*

Once again, Scenario 3 also provides a new north-south axis with connections to the M3 highway to the north and the Töginger Straße Autobahn to the south. The difference is the extra extension of the Humboldtstraße from Dornach which serves the spread of the eastern settlements. The new links included into the existing private transport are shown in red in Figure 27.

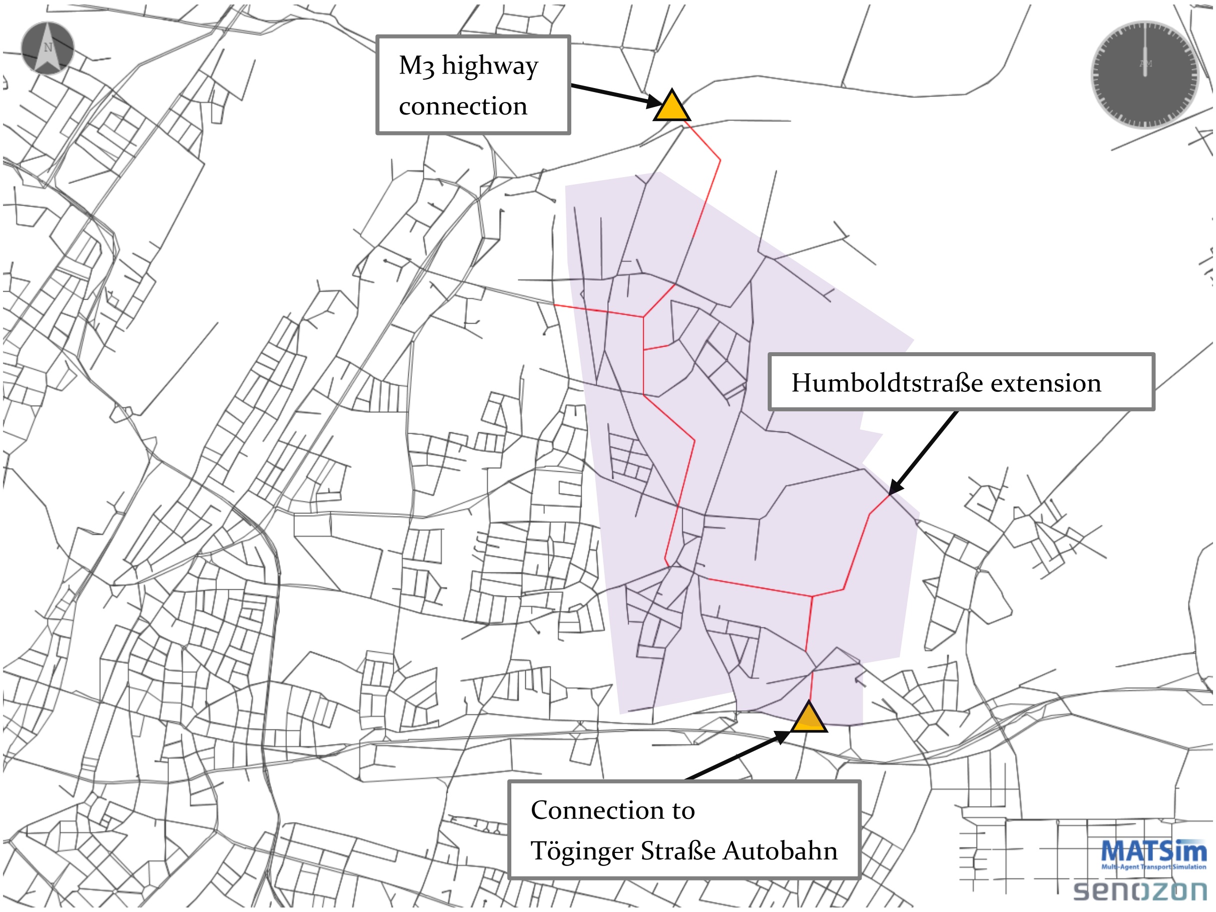



Figure 27 MATSim Private Transport Network of the Northeast – Scenario 3

The figures for the private transport networks simply show the links with no background for clarity. Appendix D provides the private transport network with a base map aligned in behind for more context.

## 8.3 Public Transport Network

Each scenario proposes an extension of the U4 U-Bahn line from the current eastern-most stop of Arabellapark to the Northeast, via the existing S-Bahn stop of Englschalking. Following the plans of the DUPBR (Landeshauptstadt München, 2016), the new U-Bahn stations and routes are included into the current MMA public transport network. In each of the scenarios, the existing capacities and headways are used for the new links. Travel time between the stops range from 60 seconds to 100 seconds according to their distances. The travel times for each of the scenarios are shown in Appendix E.

***Scenario 1***

The extension of the U4 line for Scenario 1 is shown in Figure 28. There are essentially two completely new stations and an existing station (Englschalking) that will provide an extra connection. This is at the S-Bahn station Englschalking, where a new link between S-Bahn (S8) and U-Bahn (U4) is established. One of the new stations is positioned in between Arabellapark and Englschalking and the second in the core of the proposed settlement area of the Northeast.

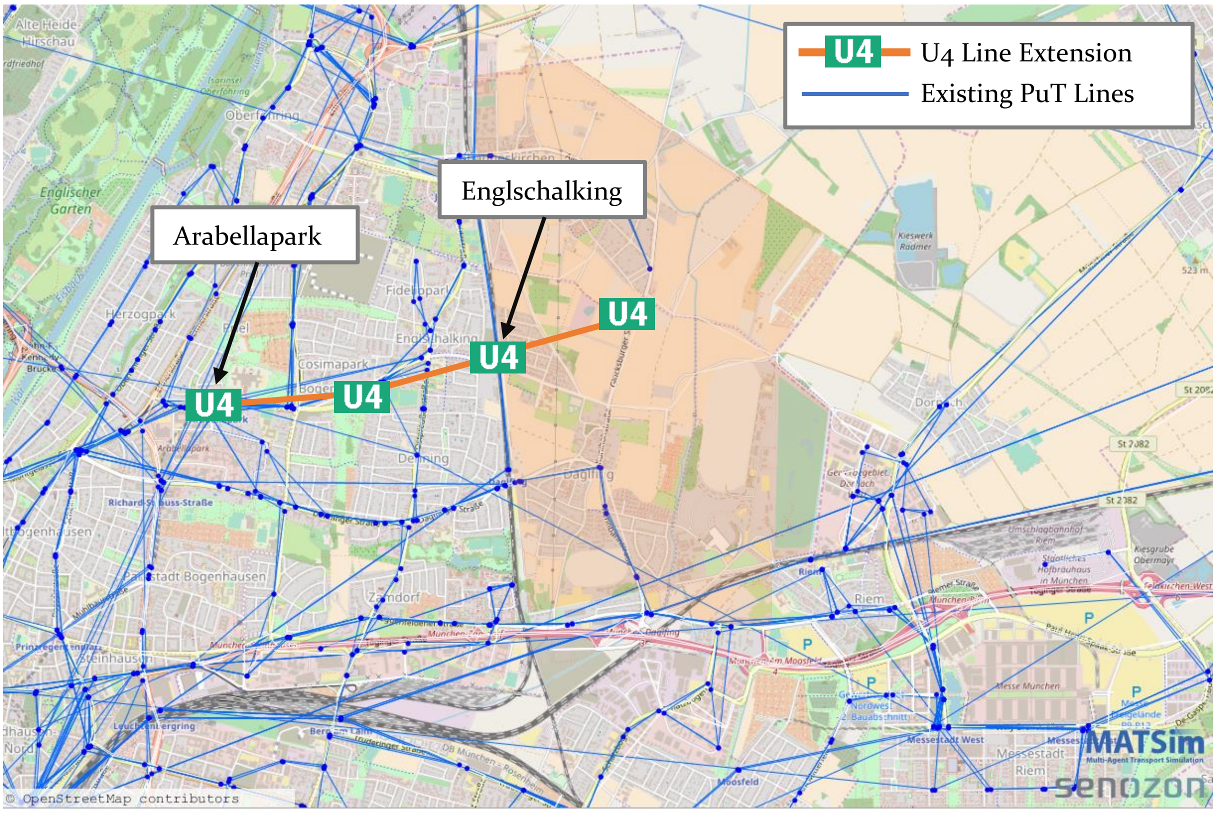



Figure 28 MATSim Public Transport Network of the Northeast – Scenario 1

### *Scenario 2*

The extension of the U4 line for Scenario 2 is shown in Figure 29. Scenario 2 envisions the U4 line to extend eastwards from Arabellapark to the core of the Northeast via Englshalking and extend further south to Riem and Messestadt West. Two new stations are required with the proposal and four stations (Arabellapark, Englschalking, Riem and Messestadt West) gain a new link.

A new link between S-Bahn (S8) and U-Bahn (U4) is established at the S-Bahn station Englschalking. The U4 further crosses the S-Bahn line S2 at Riem and then terminates at Messestadt West which serves the U-Bahn lines U1, U2 and U8. This extension is regarded as an important network completion, closing the eastern gap of Munich. This not only provides the Northeast with excellent connection, but provides additional connections for the neighbouring areas. One of the new stations is positioned in between Arabellapark and Englschalking and the second in the core of the proposed settlement area of the Northeast.

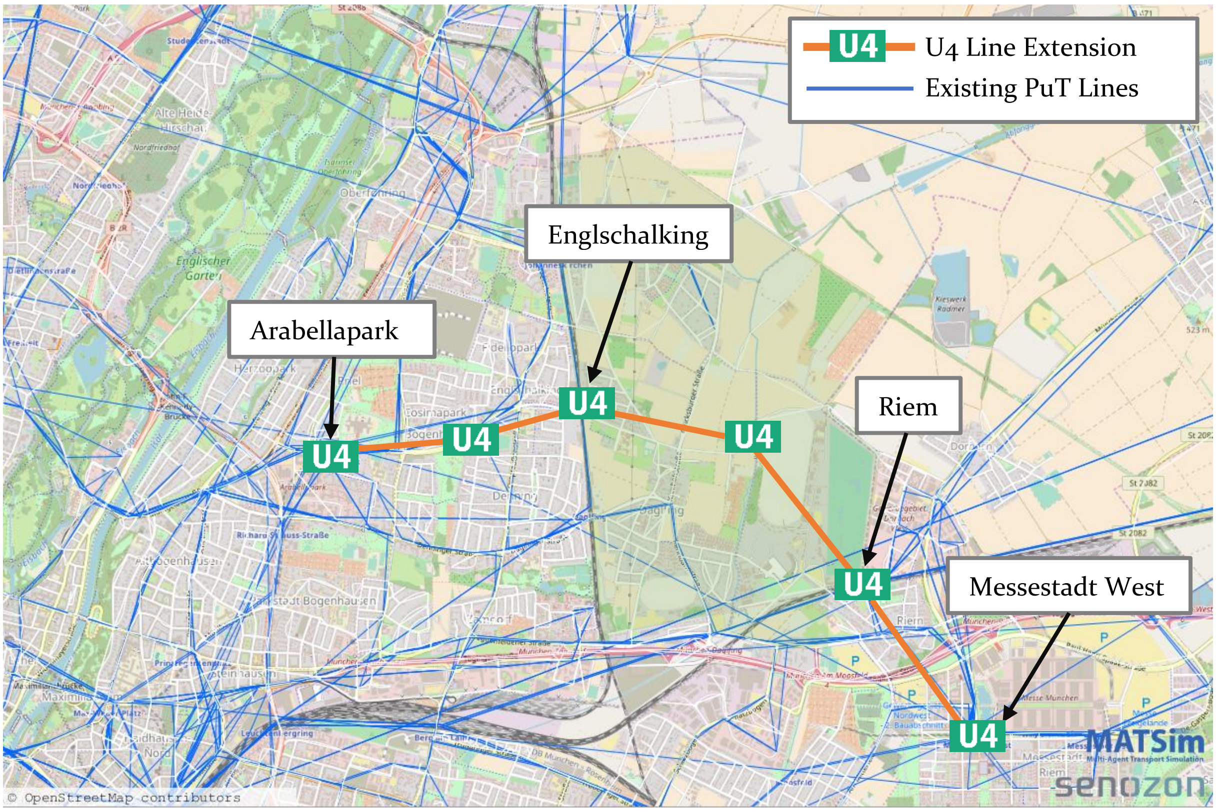



Figure 29 MATSim Public Transport Network of the Northeast – Scenario 2

***Scenario 3***

The extension of the U4 line for Scenario 3 is shown in Figure 30. Similarly, to Scenario 2, Scenario 3 envisions the U4 line to extend eastwards from Arabellapark to the core of the Northeast via Englshalking and extend further south to Riem and Messestadt West. Here, three new stations are required with the proposal and the same four stations (Arabellapark, Englschalking, Riem and Messestadt West) gain a new link.

Again, a new link between S-Bahn (S8) and U-Bahn (U4) is established at the S-Bahn station Englschalking. The U4 further crosses the S-Bahn line S2 at Riem and then terminates at Messestadt West which serves the U-Bahn lines U1, U2 and U8. The difference with this scenario is that there are two new stations in the Northeast area due to the structure of the proposed settlements with this scenario. One is just east of Englshalking and the other is north of Riem.

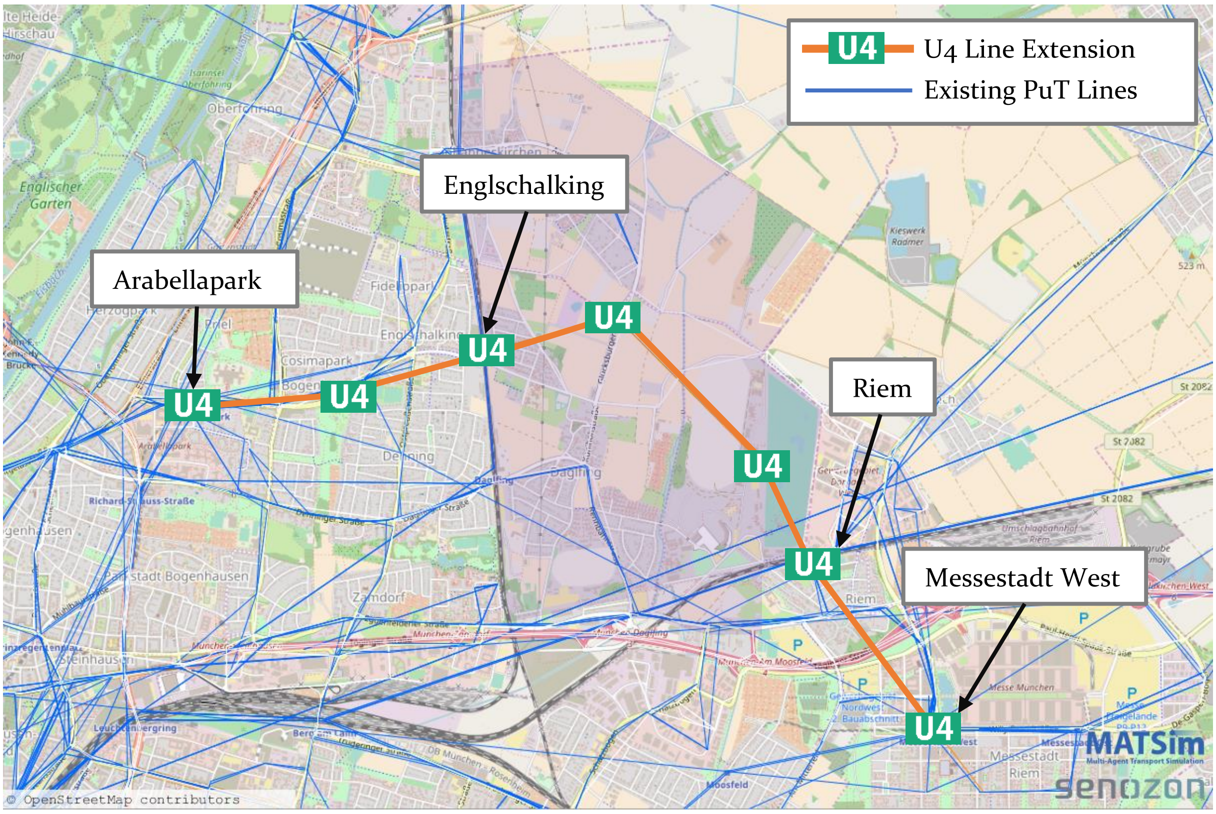



Figure 30 MATSim Public Transport Network of the Northeast – Scenario 3

# 9 Modelling Results and Discussions

This section presents the final modelling results and their corresponding points of discussion. The properties analysed for the assessment of the land use and transport impacts of the Northeast Munich urban development are the following:

- Population – number of people
- Dwellings – number of dwellings available
- Dwellings Occupied – percentage of dwellings occupied (number of households / number of dwellings)
- Average Price – average monthly costs of a dwelling
- Employment – number of jobs available
- Accessibility – level of accessibility by private vehicle and by public transport

Each property is analysed for the areas:

- MMA Study Area (neglected in some cases)
- Northeast Area

And for each scenario:

- Base scenario
- Scenario 1
- Scenario 2
- Scenario 3

## 9.1 Population

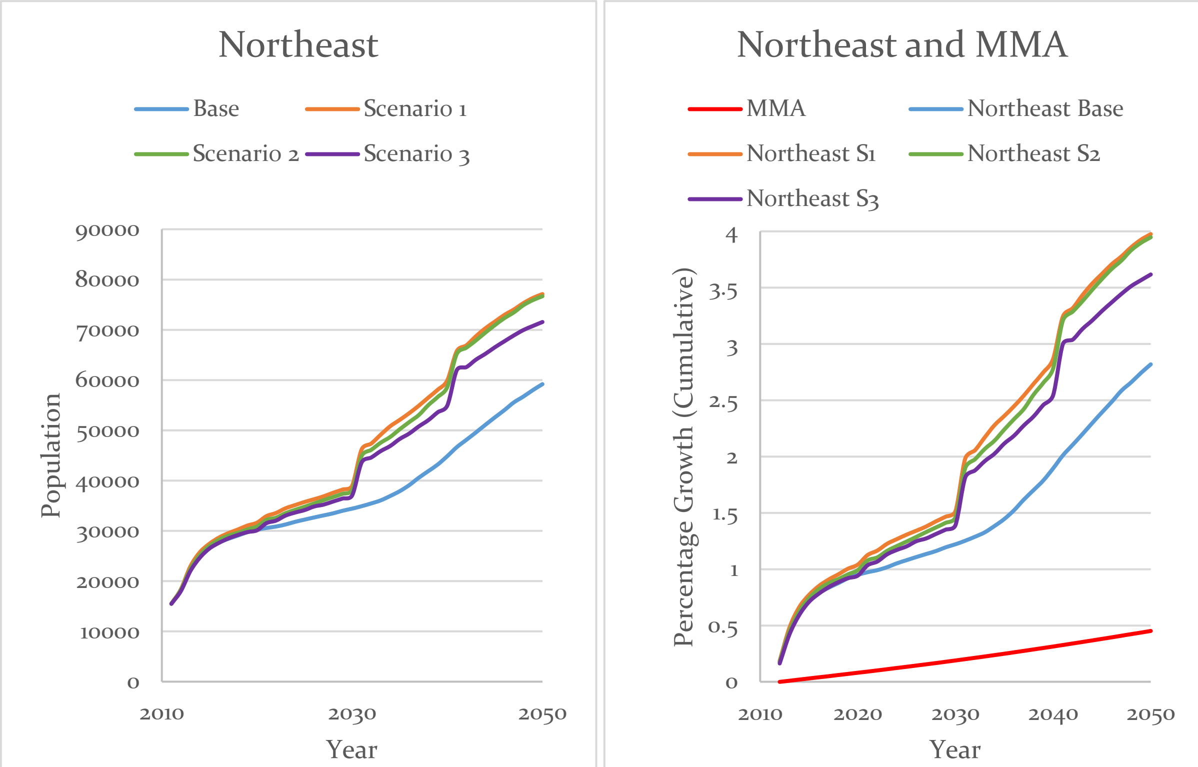



Figure 31 Population Growth – MMA and Northeast

As expected, population increases for all scenarios including the base scenario as shown in Figure 31. Sharp peaks are seen at year 2020, 2030 and 2040 for all three Northeast scenarios where people move into the new dwellings that have been constructed. Another peak is expected in population increase soon after 2050 as new dwellings are also constructed in 2050 with the proposals.

The cumulative percentage growth of the population between the years 2011 and 2050 show that population in the Northeast almost quadruples with Scenarios 1 and 2. Scenario 3 also increases significantly and expects an increase of over 3.5 times the initial population. The degree of the population increase in Northeast is evident when compared with that of the MMA. The cumulative percentage increase of population in the MMA almost reaches 0.5, i.e. a 50% increase in 2050 compared to 2011. This is an eighth of the increase in the Northeast.

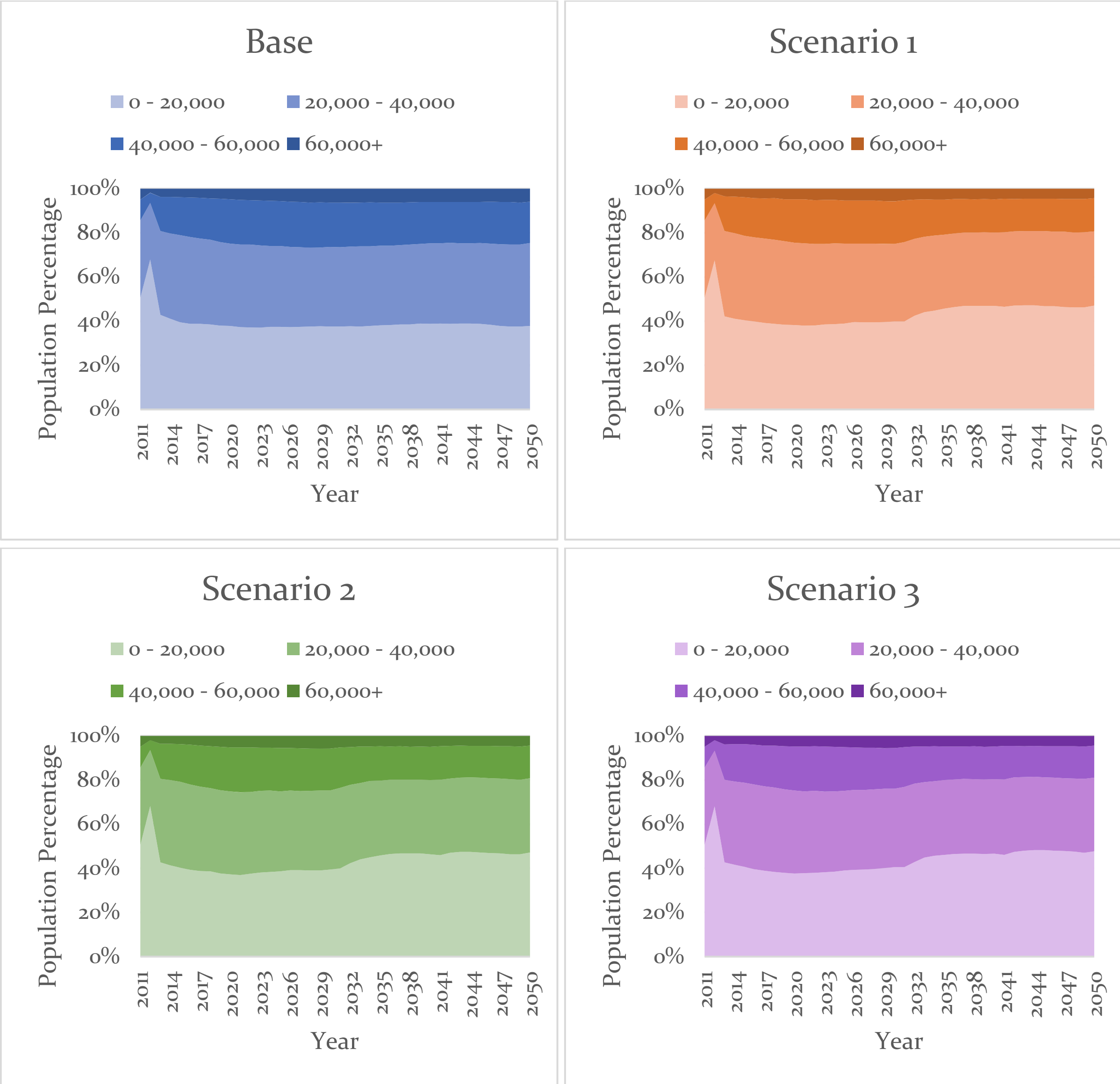



Figure 32 Population by Income – Northeast

Population as a percentage by income for the Northeast area is shown in Figure 32 for each of the scenarios. There are four income groups: 0 – 20,000; 20,000 – 40,000; 40,000 – 60,000; and 60,000+ euros per month. There is a sudden peak of lower income groups in 2012 followed by a drop directly after in 2013. This can be regarded as an outlier corresponding to the unexpected high numbers of jobs in the Northeast in 2011. This error is described in the employment results, Chapter 9.5 Employment.

Apart from the initial peak in 2012, the proportions of each income group are relatively stable throughout the years. There is a slight increase in lower income groups from the year 2030 onwards for the three development scenarios. This is probably due to the increased capacity in the Northeast allowing lower income groups to move into the area.

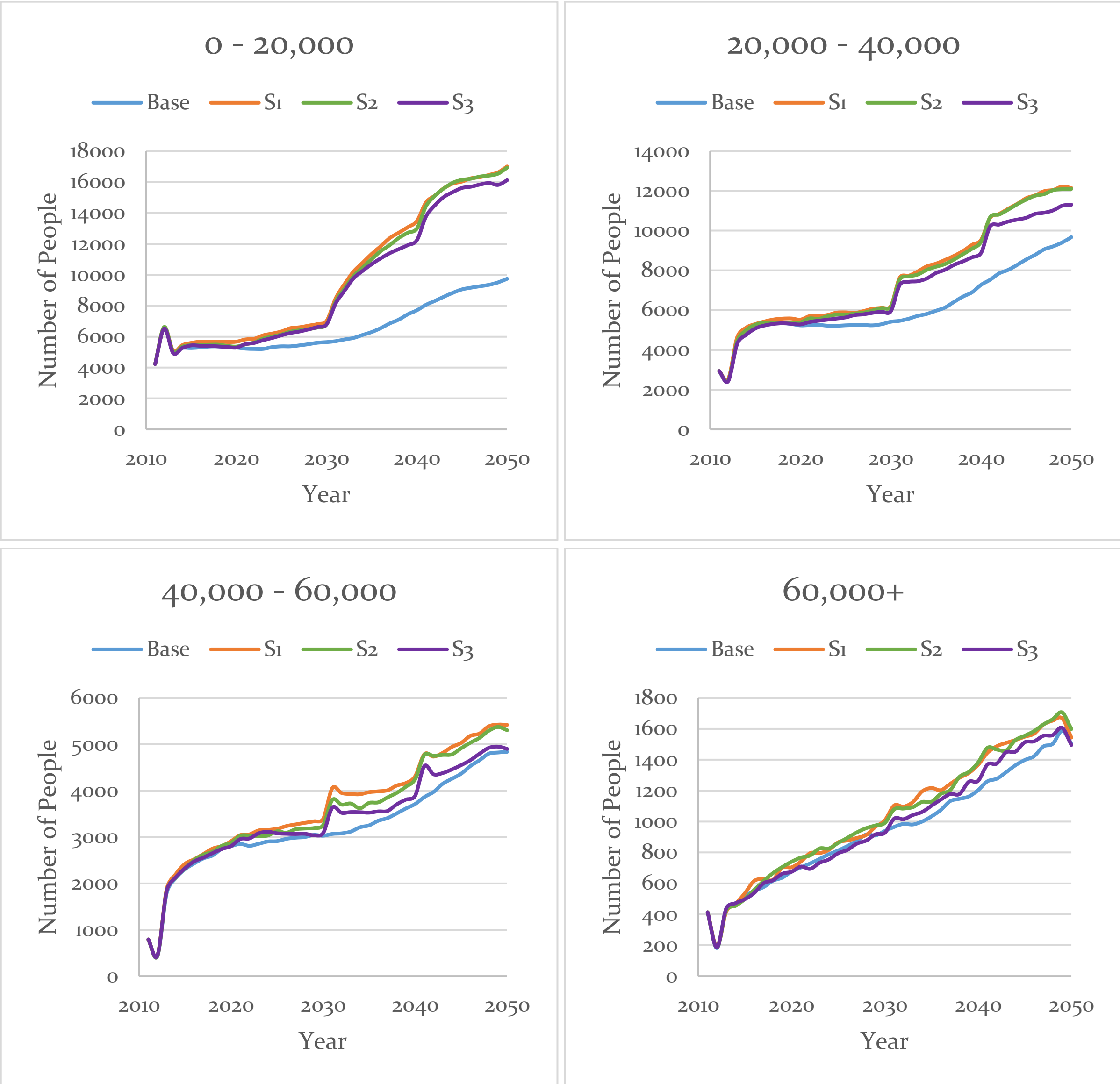



Figure 33 Number of People by Income Group - Northeast

A similar comparison is done for the increase in the number of people for each income group for each scenario in Figure 33. Each income group shows a steady increase in the number of people which is an expected result with the overall population increase in the Northeast.

Sharp increases in the number of people are also seen here when new dwellings are introduced in the years 2020, 2030 and 2040. Particularly interesting to see the higher numbers of people in the lower income groups (0 – 20,000; 20,000 – 40,000) compared to the higher income groups (40,000 – 60,000; 60,000+) for the developing scenarios compared to the base. This suggests that there are more people in the lower income groups moving into the Northeast than the higher income groups.

The gap between the scenario forecasts and the base is largest in the lowest income group (0 – 20,000) followed by the second lowest (20,000 – 40,000) and second highest (40,000 – 60,000). The highest income group (60,000+) shows that increases in the number of people are similar for all scenarios. Another interesting point is that out of the three scenarios, Scenario 1 and 3 show a relatively similar increase in all income groups and has higher numbers of people for all income groups. This means that more people are moving into the new dwellings created in the Northeast with Scenarios 1 and 3 than that of Scenario 2.

Once again, in the initial years at 2012 either a sharp increase followed by a sharp decrease or a sharp decrease followed by an increase of people are seen in each of the income groups. The number of people in the lowest income group (0 – 20,000) experiences a sudden increase in 2012 and then a decrease in 2013. In all other income groups, there is a sudden decrease and then an increase in the number of people. These initial peaks are suspected to be an issue in the 2011 synthetic population where the number of jobs set for the synthetic population in 2011 is an older estimate. The employment estimate for 2011 has not been overwritten for the synthetic population in 2011, thus a huge limitation of the model. Nevertheless, employment numbers from 2012 onwards have been successfully overwritten and thus is relevant. Again, this limitation is described further in Chapter 9.5 Employment.

***Visualising Population Change***

Figure 34 and Figure 35 visualises the changes in population for each of the scenarios for the Northeast. The number of people per zone is shown at approximately 20 year intervals starting from 2011, then 2030 and finally in 2050.

Population growth is evident in all scenarios with the base scenario showing the least change. The population growth with scenarios show a greater change. The change is especially evident in the zones within the development boundaries (the development boundaries are shown).

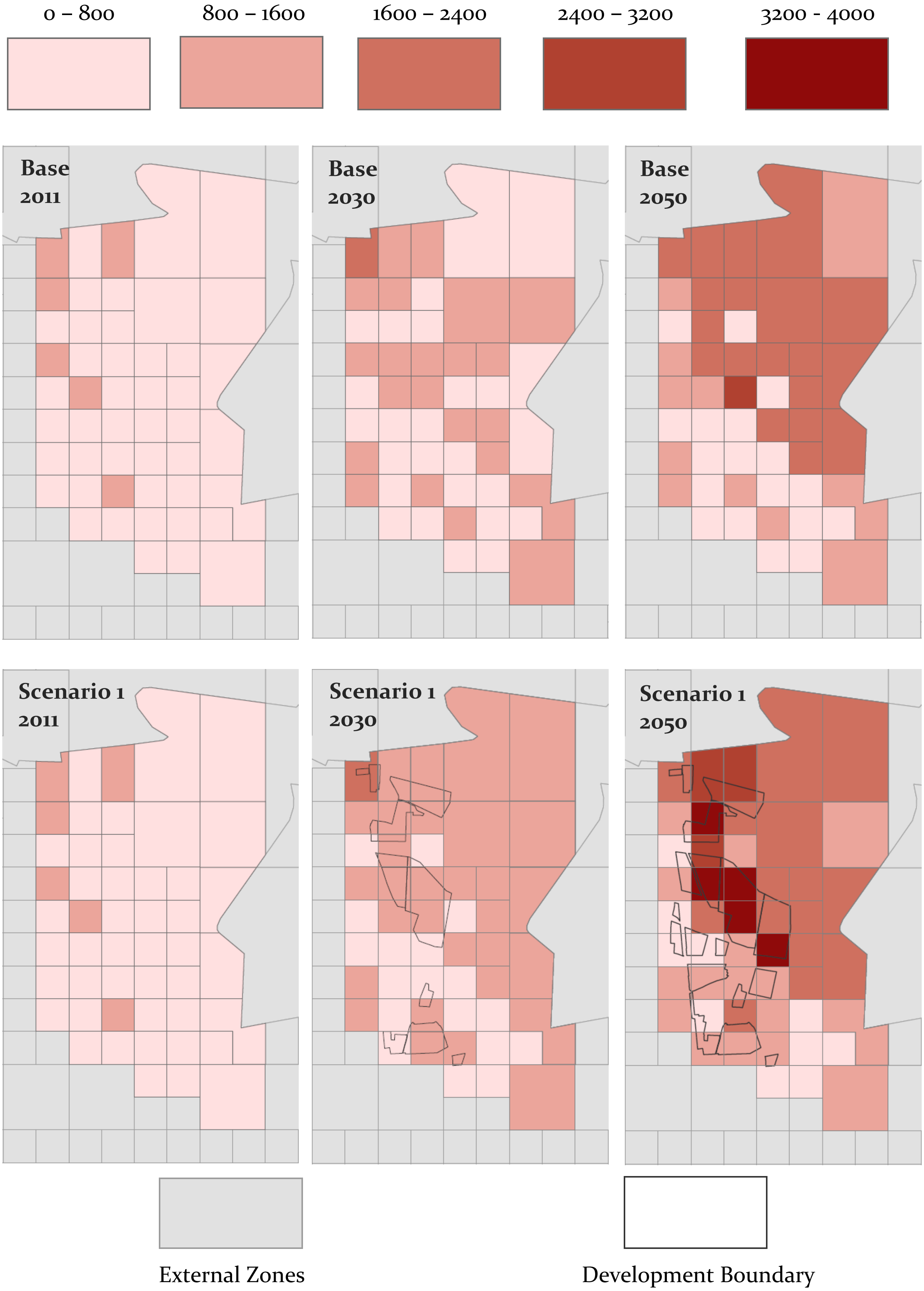



Figure 34 Northeast Munich Population Growth – Base and Scenario 1

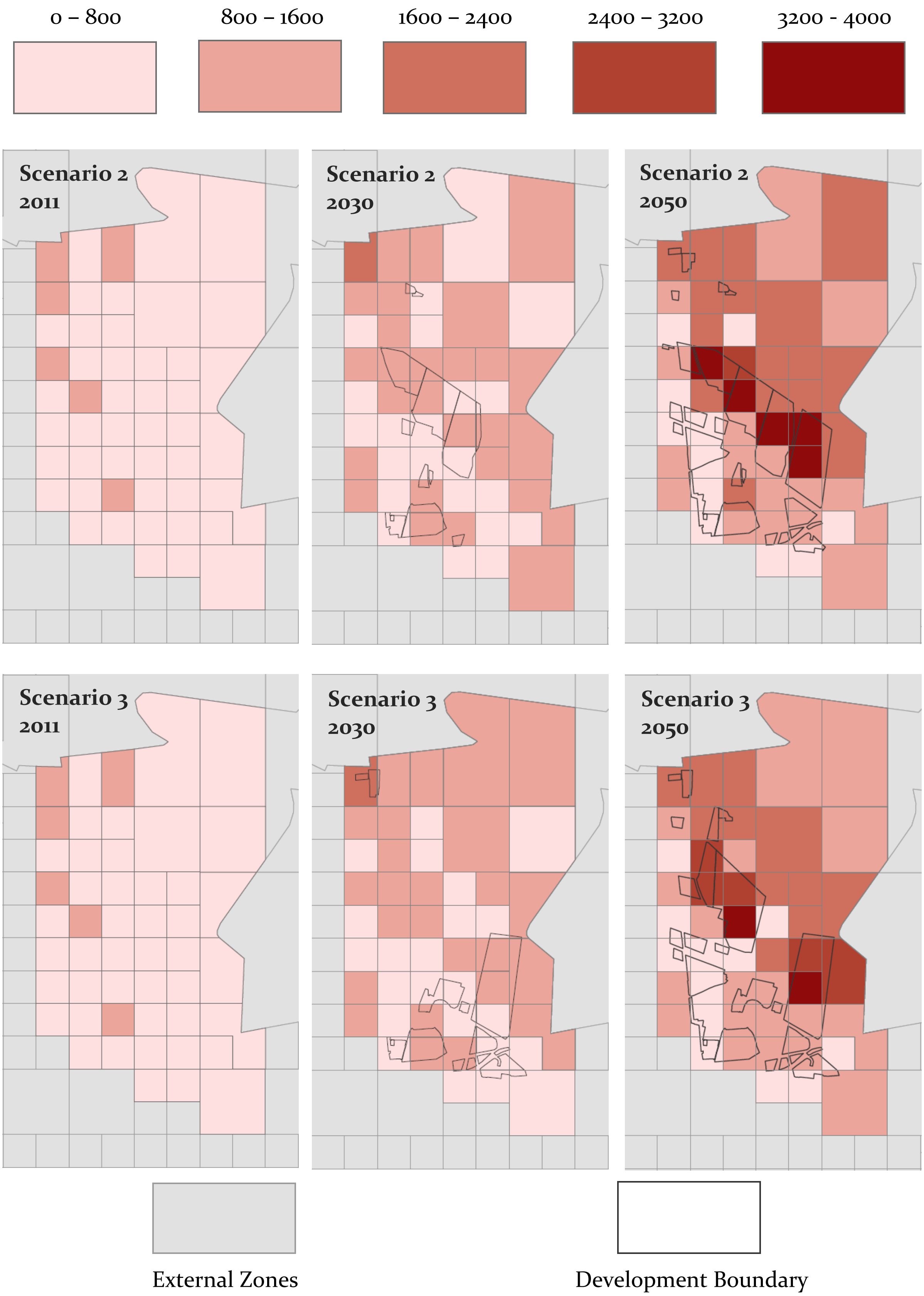



Figure 35 Northeast Munich Population Growth – Scenario 2 and Scenario 3

## 9.2 Dwellings

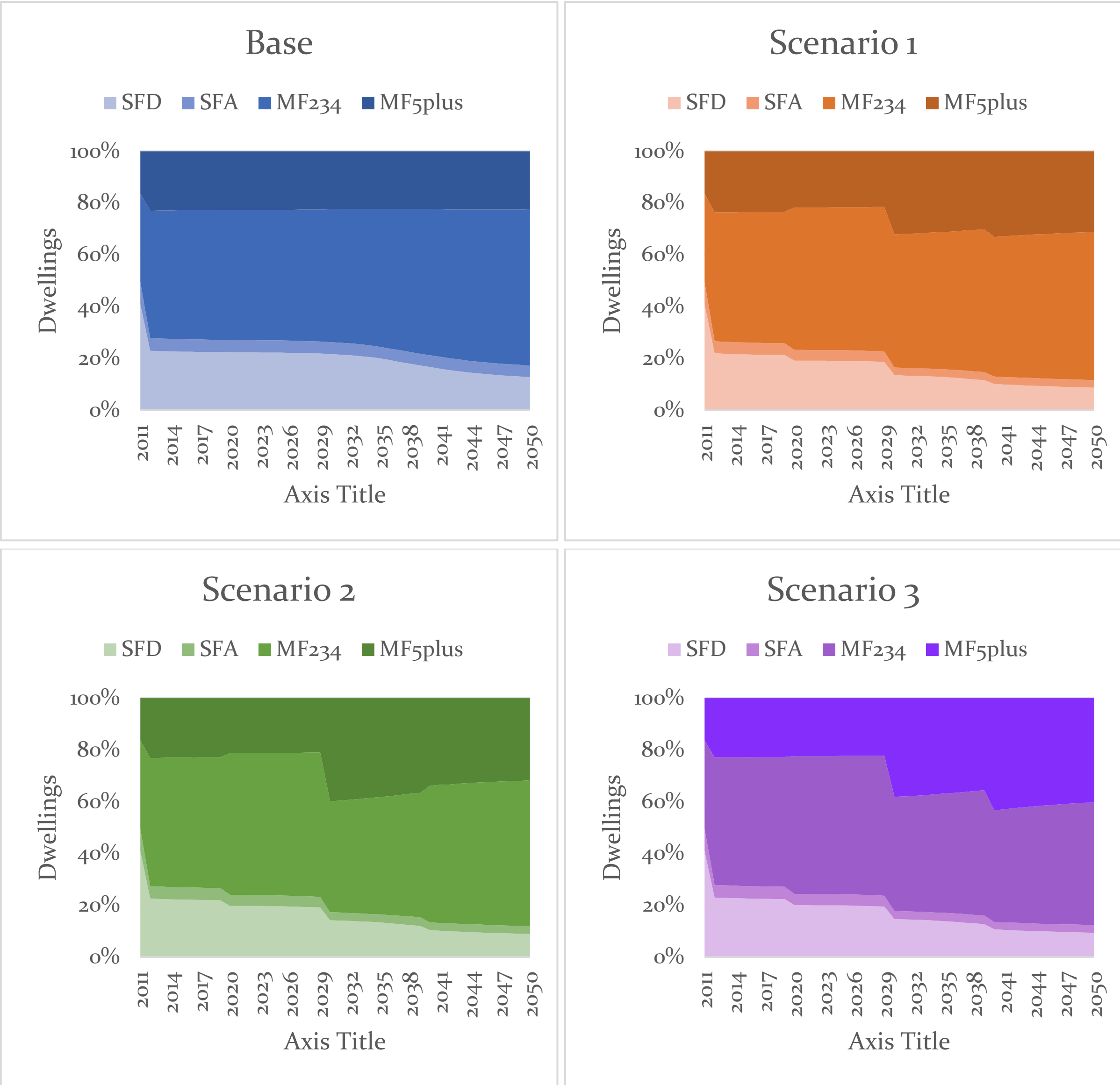



Figure 36 Dwellings by Type – Northeast

A proportion of the dwellings by dwelling types in the Northeast is shown in Figure 36. The dwelling types are SFA, SFA, MF234 and MF5plus. Dwelling type MH has not been considered in the evaluation as no zones in the Northeast has MH type dwellings.

Firstly, all scenarios show a sudden change during 2011-2012 where the proportion of MF234 and MF5plus increase substantially, resulting in decreasing the proportion of SFD and SFA dwellings. This is due to the sudden increase in MF234 and MF5plus dwellings in the year 2012 which is irrelevant to the proposed settlements of the Northeast. The increase in the share of dwelling types MF234 and MF5plus are evident for years 2030 and 2040 for the development scenarios.

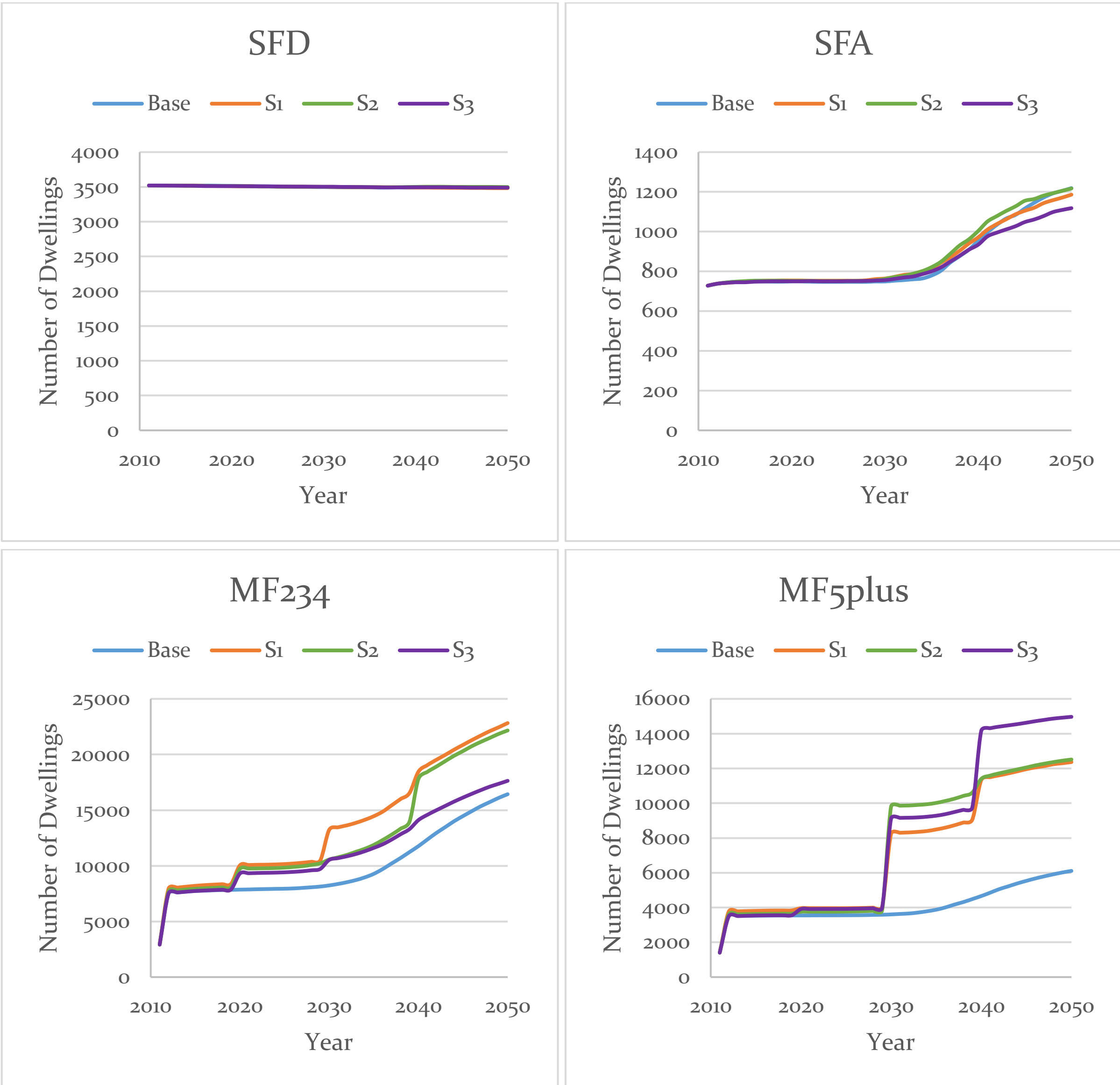



Figure 37 Number of Dwellings by Dwelling Type - Northeast

The number of dwellings by dwelling types across the years are analysed for each scenario in Figure 37. There is almost no change in the number of SFD dwellings in the Northeast. The number of SFAs are constant until 2030 when a gradual increase is seen.

The exogenous addition of dwellings with the development scenarios only include MF234 and MF5plus type dwellings. The construction of these dwellings is shown clearly in the graph for MF234 and MF5plus. Peaks of increase in dwellings are seen for the years 2020, 2030 and 2040. Another peak is expected after 2050 with the addition of dwellings in the year.

The initial peak in the number of MF234 and MF5plus dwellings between 2011 and 2012 is suspected to be due to the employment outlier in 2011.

### *Visualising Changes in the Number of Dwellings*

Figure 38 and Figure 39 visualises the changes in the number of dwellings for each scenario for the Northeast. The number of dwellings per zone is shown at approximately 20 year intervals starting from 2011, then 2030 and finally in 2050.

The increase in the number of dwellings is evident in all scenarios with the base scenario showing the least change. The increase in the number of dwellings is greater with the three scenarios as expected with the exogenous addition of dwellings with the proposal. This increase is especially apparent in the zones within the development boundaries.

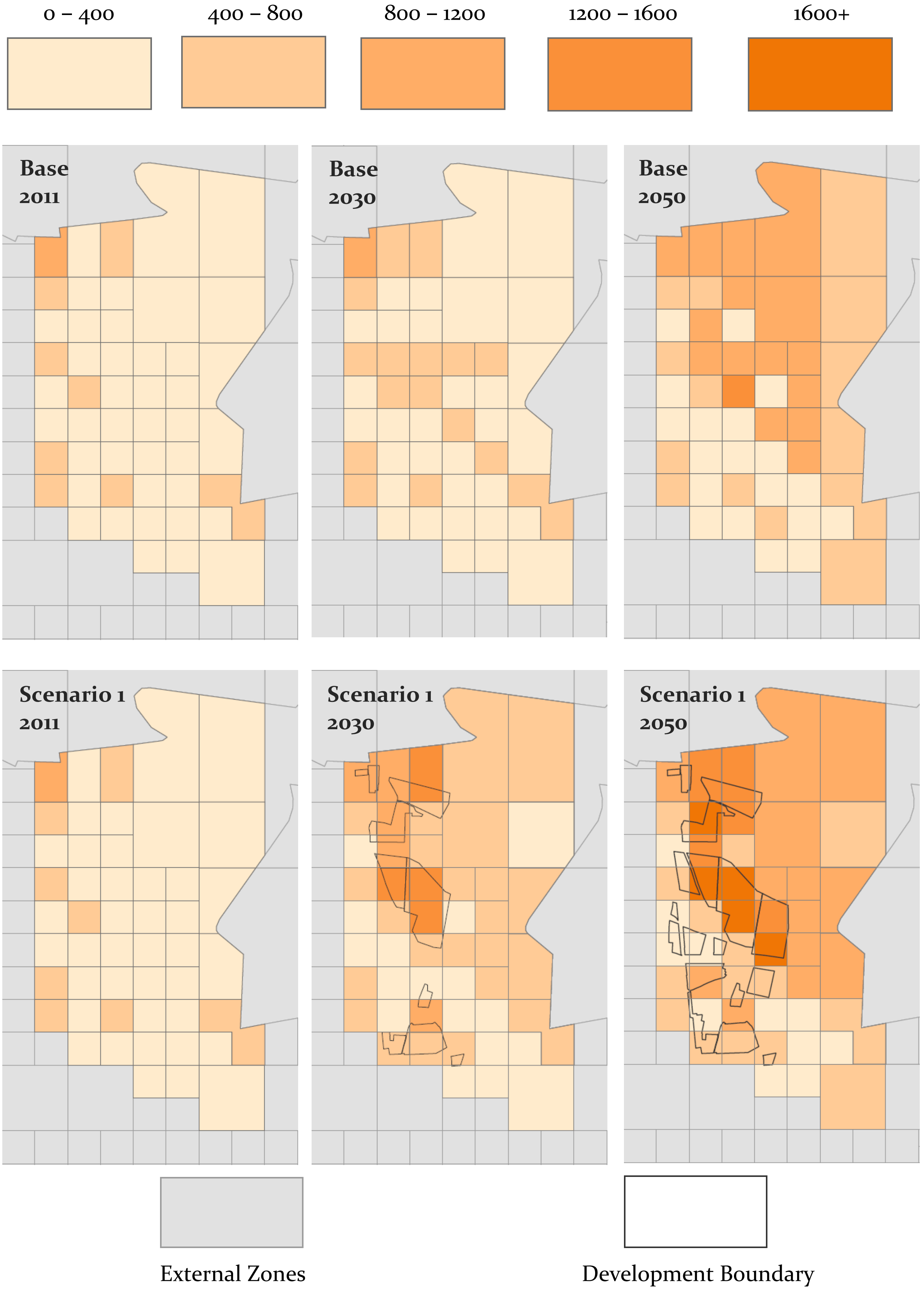



Figure 38 Northeast Munich Dwellings – Base and Scenario 1

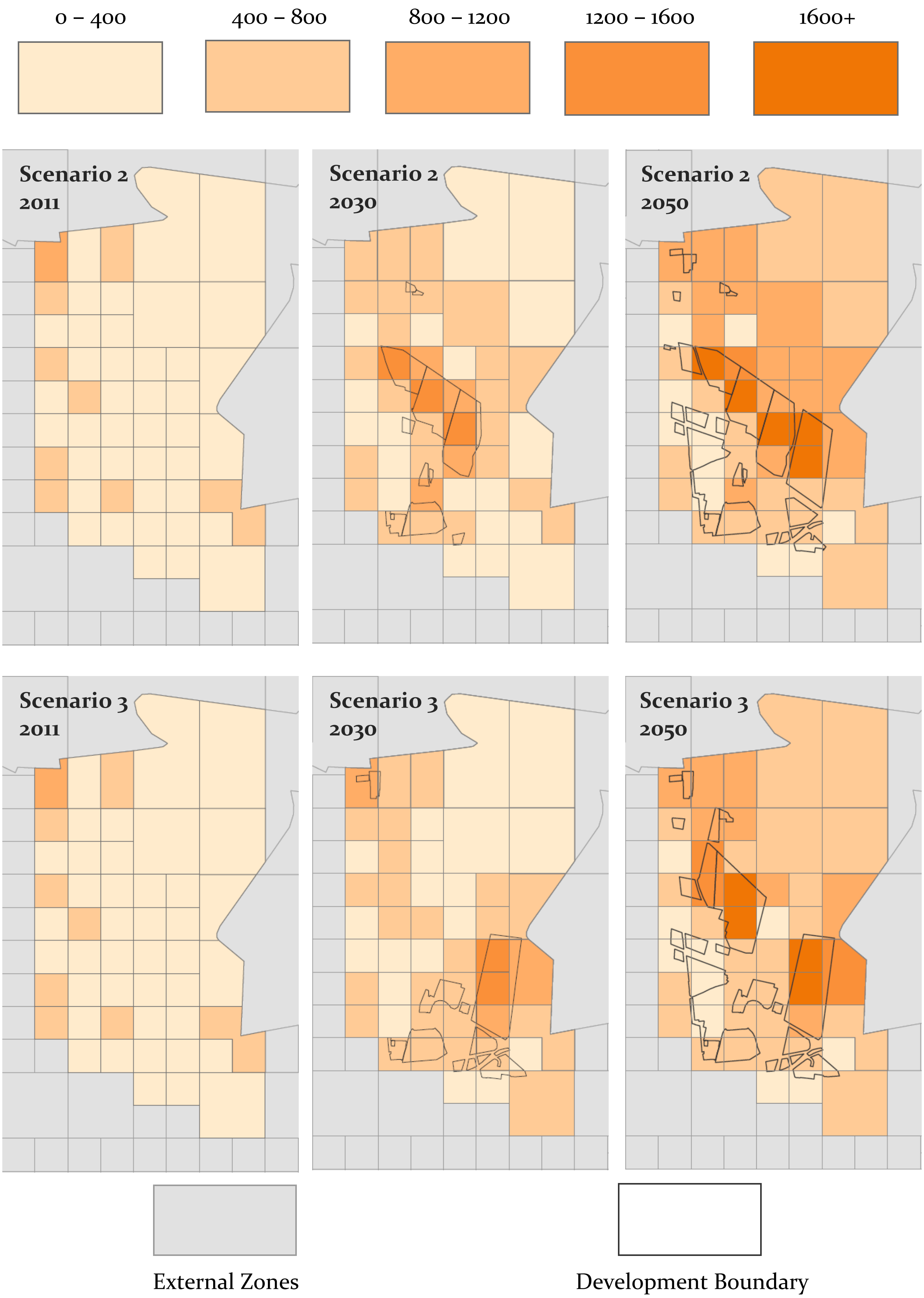



Figure 39 Northeast Munich Dwellings – Scenario 2 and Scenario 3

## 9.3 Dwellings Occupied

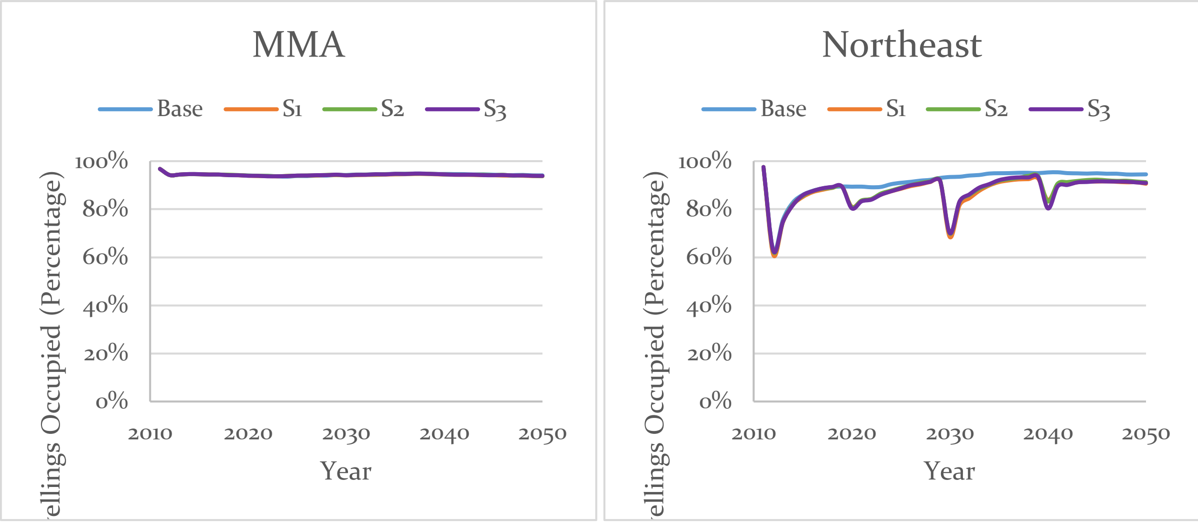



Figure 40 Dwellings Occupied (Percentage) – MMA and Northeast

The percentage of dwellings occupied are analysed for the MMA and the Northeast in Figure 40. The percentages in the MMA show a relatively stable occupancy rate across the years for all scenarios. The percentages in the Northeast resemble the effect of new dwellings being constructed into the area in the years 2020, 2030 and 2040. The addition of new dwellings brings down the percentage of occupancy as there are many more dwellings than the respective number of households for the affected years. However, these new dwellings are seen to become occupied at an extremely fast pace which is represented by the increase in occupancy immediately after the drop. The final (2050) occupancy rate of all development scenarios are slightly less than that of the base scenario, suggesting a tapering of the initial high housing demands.

There is also a sudden drop in the occupancy rate in 2012 which is due to the large number of new dwellings constructed in the earlier years, irrespective of the development scenarios.

***Visualising Changes in Dwellings Occupied***

Figure 41 and Figure 42 visualises the changes in the percentage of dwellings occupied for each scenario for the Northeast. The percentage of dwellings occupied per zone is shown at approximately 20 year intervals starting from 2011, then 2030 and finally in 2050.

The increase in occupied dwellings is evident in all scenarios with the base showing the highest occupancy rate over the years. Initially there are many zones that do not have an occupancy rate due to the absence of dwellings. This changes throughout the years when new dwellings are built in the Northeast. Those zones with large number of new dwellings with the scenarios show a lower occupancy rate, as evident in all scenarios in 2030 and 2050. This is due to the increased number of dwellings compared to the current number of households in the area. As mentioned before, these new dwellings become occupied at an extremely fast pace.


Figure 41 Northeast Munich Dwellings Occupied – Base and Scenario 1


Figure 42 Northeast Munich Dwellings Occupied – Scenario 2 and Scenario 3

## 9.4 Average Price

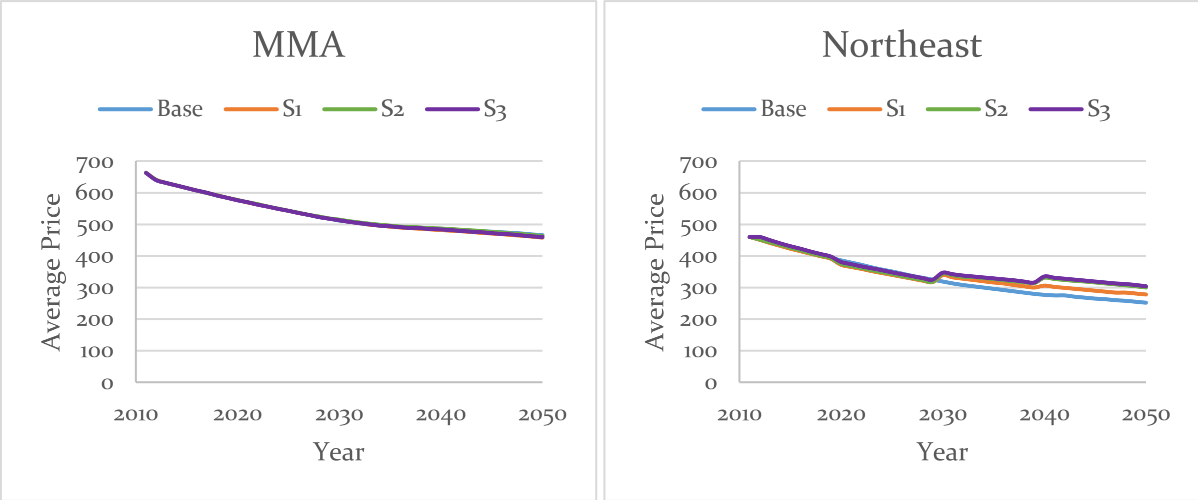



Figure 43 Average Price – MMA and Northeast

The average price, or the monthly costs (rent) is shown for the MMA and the Northeast over the years for each scenario in Figure 43.

All areas show a gradual decrease in the rent value of dwellings. The average prices for the Northeast also decrease however there are moments of slight increases with the development scenarios. This occurs when new dwellings are added in the years 2020, 2030 and 2040. The situation is unrealistic as one would expect a decrease in prices with an increased supply of dwellings. This increase is possibly a result of adding exogenous dwelling cost data (that were estimated using 2011 values) at the development years which would increase the average costs in the Northeast area substantially.

Nevertheless, the Northeast has the lowest average prices in every scenario compared to the average values for the MMA and the Neighbour area, as shown in Figure 44.

The reader must understand that the average prices shown are not a validated value against the current real estate market prices for dwellings in Munich. As mentioned in Chapter 7.5.1, the land prices (thus rent prices) have been estimated using the figures from the *Gutachterausschuss für Grundstückswerte* 'Expert Committee for Land Values' (2015).

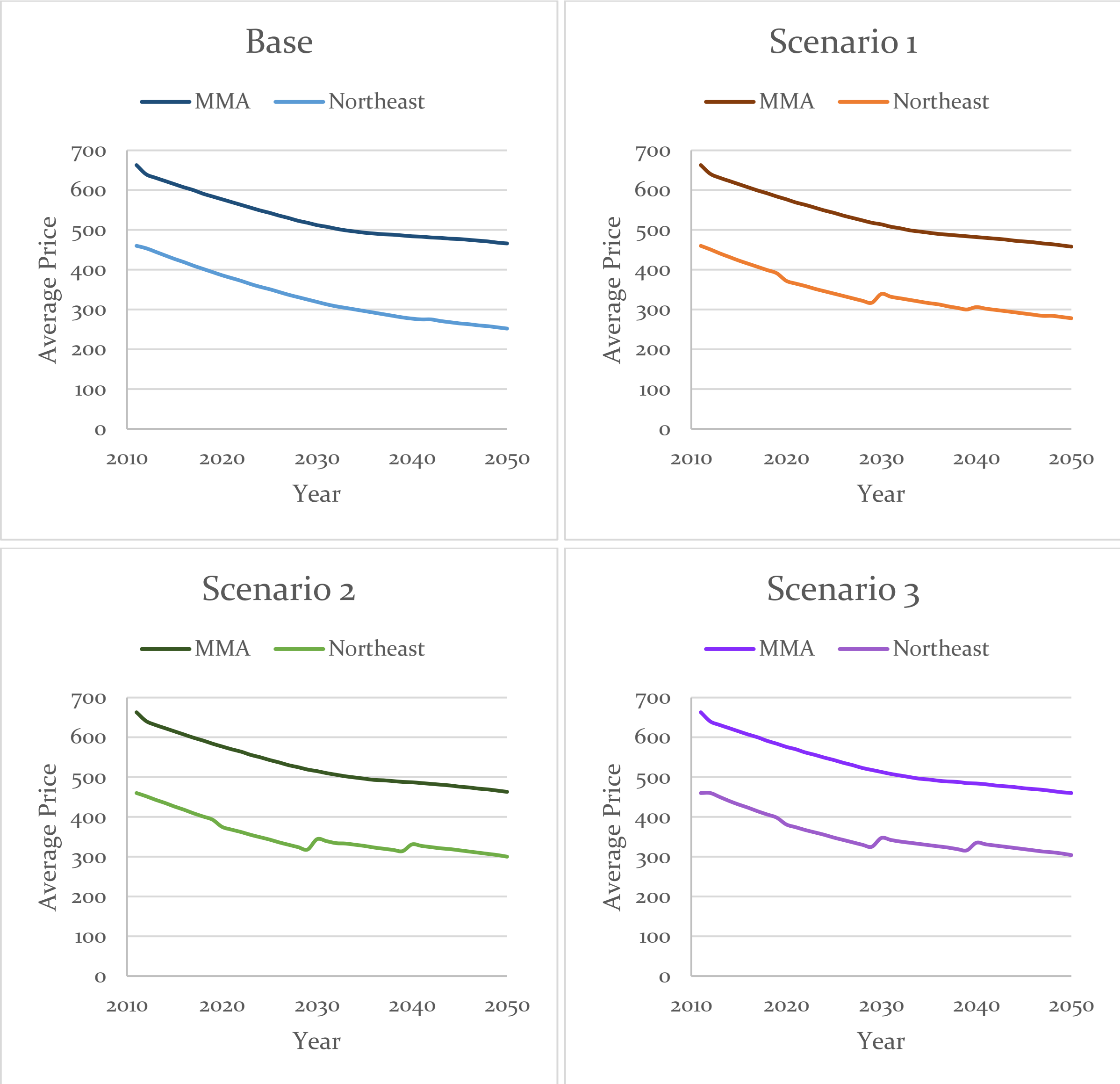



Figure 44 Average Price by Scenario – MMA and Northeast

***Visualising Changes in Average Price***

Figure 45 and Figure 46 visualises the changes in average price of dwellings for each scenario for the Northeast. The number of dwellings per zone is shown at approximately 20 year intervals starting from 2011, then 2030 and finally in 2050. Initially there are many zones that do not have any dwellings thus no average price exists.

The decrease in the average price is evident in all scenarios with the base scenario showing the most change. The changes with the development shows a higher average price which is unrealistic as mentioned with Figure 43. Here, the exogenous addition of dwellings and their corresponding prices (prices used to estimate for 2011) increases the average prices of dwellings for the zones. Thus, the zones with development shows a higher average price for all development scenarios.


Figure 45 Northeast Munich Dwellings – Base and Scenario 1


Figure 46 Northeast Munich Dwellings – Scenario 2 and Scenario 3

## 9.5 Employment

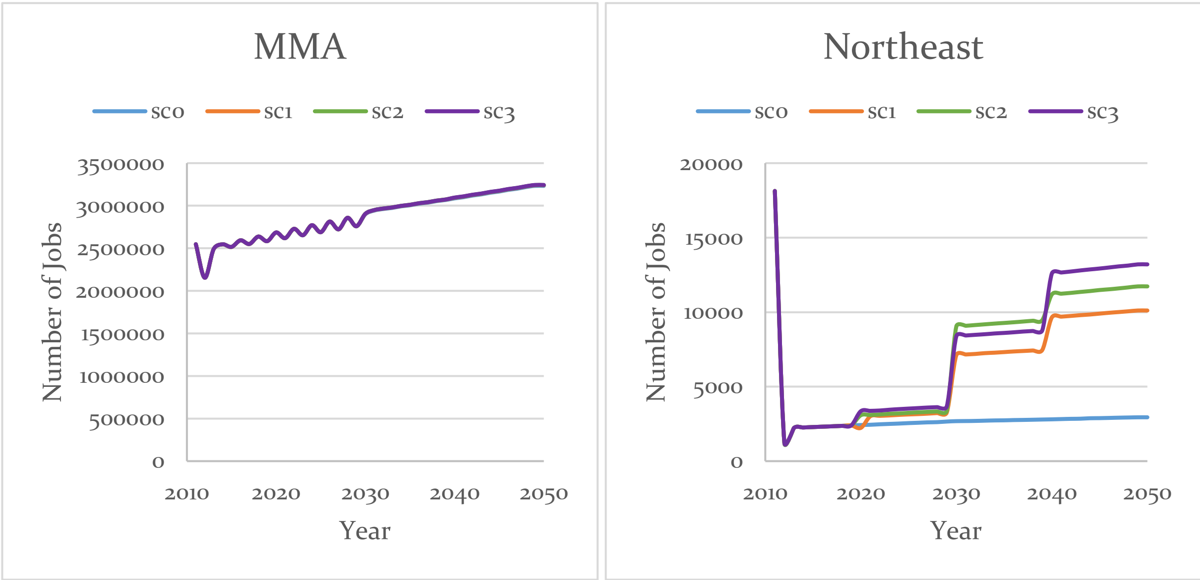



Figure 47 Employment (Number of Jobs) – MMA and Northeast

The changes in the number of jobs for the MMA and the Northeast are shown for the simulation years 2011-2050 in Figure 47.

In both the MMA and the Northeast, there seems to be a sudden drop in jobs between the years 2011 and 2012. This is due to an error in the synthetic population (synthetic jobs) data for 2011 where initial values for employment were used. This has seemed to cause an over-estimate of population growth and the building of many MF234 and MF5plus dwellings in the earlier years. This resulted in unrealistic peaks of changes in the population when compared by income groups and a low dwelling occupancy. From 2012 onwards, the employment estimates, forecasts and scenario values described in Chapter 7.6 are relevant.

Number of jobs in the model are exogenous values for the years 2020, 2030, 2040 and 2050. The number of jobs in between these years are interpolated between the known values. The graph of the number of jobs for each scenario in the MMA shows a undulating increase from 2012 to 2030. This is due to the applied 'Trend' scenario for employment forecast (Chapter 7.6.2 Employment Forecast). In constrast, the 'Basis' scenario is applied for the years between 2030 and 2050, showing the gradual increase.

The figure for the number of jobs in the Northeast represent the clear introduction of new jobs with the new settlements in years 2020, 2030 and 2040. Another sharp increase in the number of jobs is expected soon after 2050 with the addition of new jobs in the year.

As expected, Scenario 3 shows the most number of jobs in the final year, followed by Scenario 2 and then lastly Scenario 1, which is consistent with the proposed scheme. When comparing the development scenarios to the base scenario, there is a clear difference in the number of jobs in the Northeast.

***Visualising Changes in Employment***

Figure 48 and Figure 49 visualises the changes in employment for each scenario for the Northeast. The employment is shown as the number of jobs at 2020, 2030 and 2050. Note here that the first visualisation is for the year 2020 not the year 2011 as in earlier comparisons. This is due to the 2011 showing unrealistic numbers for jobs due to an error in the synthetic population for this year.

An increase in jobs is evident in all scenarios with the base scenario showing the least change. As expected, all development scenarios show an increase in jobs in zones that are within the development boundary.

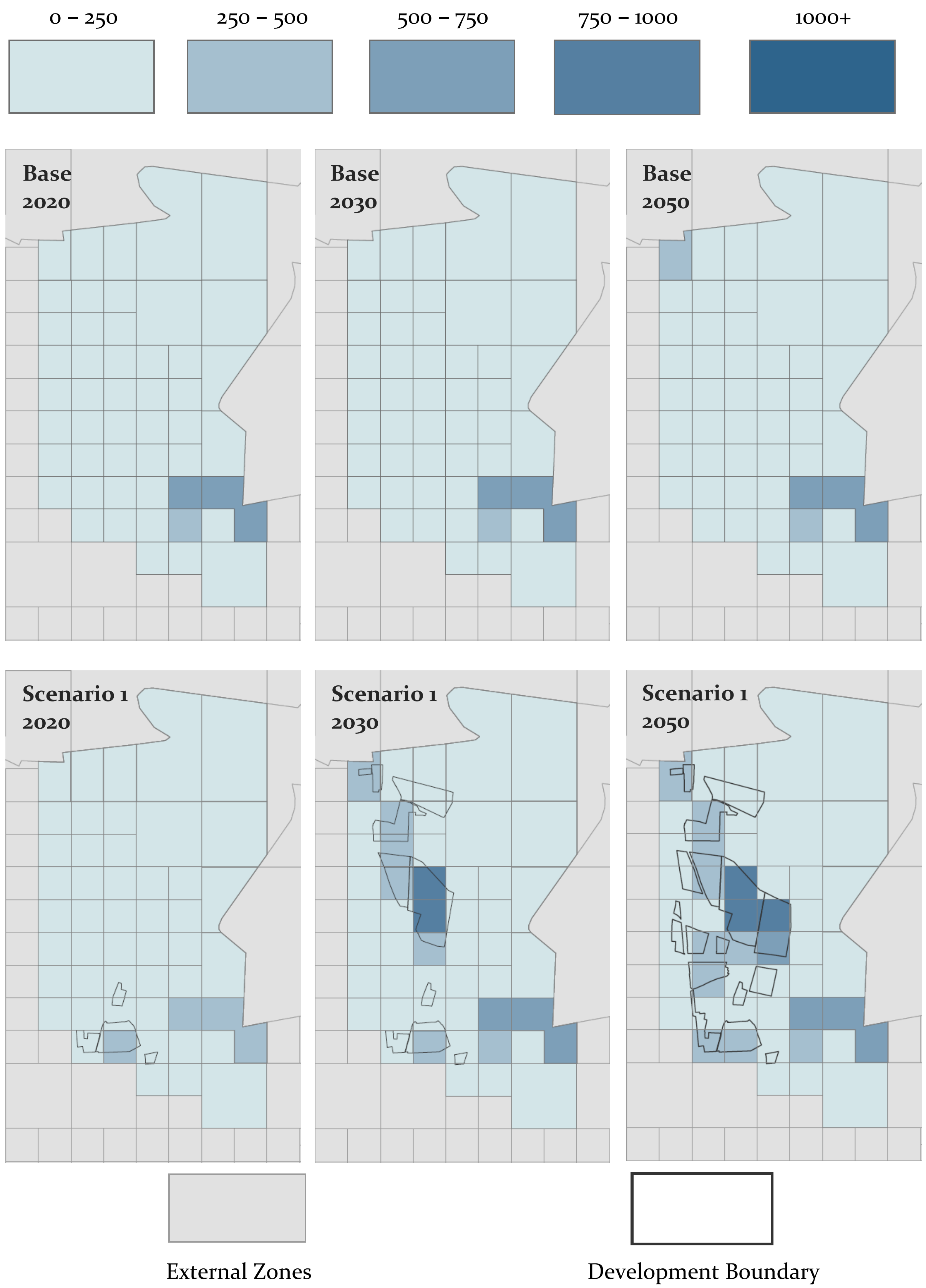



Figure 48 Northeast Munich Dwellings – Base and Scenario 1

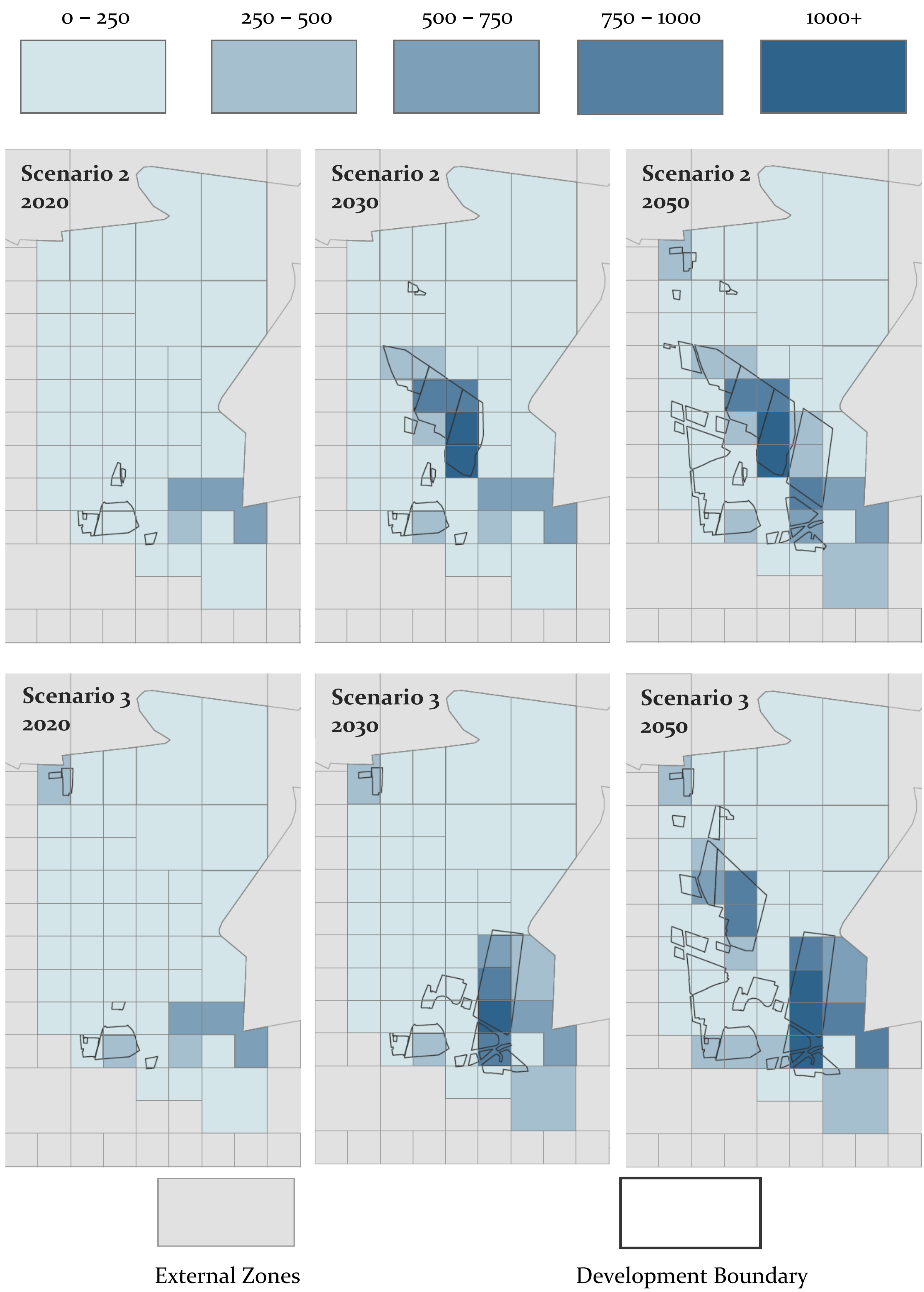



Figure 49 Northeast Munich Dwellings – Scenario 2 and Scenario 3

## 9.6 Accessibility

Accessibility results have been normalised compared to the accessibility values for the entire MMA Study Area. Even doing so, the accessibility values for both the access by private car and by public transport are unrealistic to the point that comparisons cannot be made between the scenarios.

***Accessibility by Private Car***

- Firstly, the accessibility values do not change throughout the years from 2011 to 2050 even with the new private transport network. This is an error of the model as new accessibility values should be calculated yearly for each zone.
- Additionally, although there is some difference in values between the scenarios, once compared, the accessibilities do not represent the new transport networks. For example, the results suggest that the accessibility to the Northeast is lower in Scenario 3 than the Base scenario. This is not realistic especially when new roads are built.
- The accessibility results for private car (although not valid) are shown in Figure 50.

***Accessibility by Public Transport***

- Similarly, the accessibility values for public transport do not change throughout the years for any of the scenarios from 2011 to 2050. Once again, there are some differences between scenarios, however do not represent the new public transport network scheme.
- Furthermore, a problem was found with the transit time skim matrices that were used by the model for the public transport network. Areas with no public transport connections were given the highest utility value due to this error, thus covering any improvements made in the Northeast with the development scenarios. For this reason, it was impossible to find valid results.
- The accessibility results for public transport (although not valid) are shown in Figure 51.

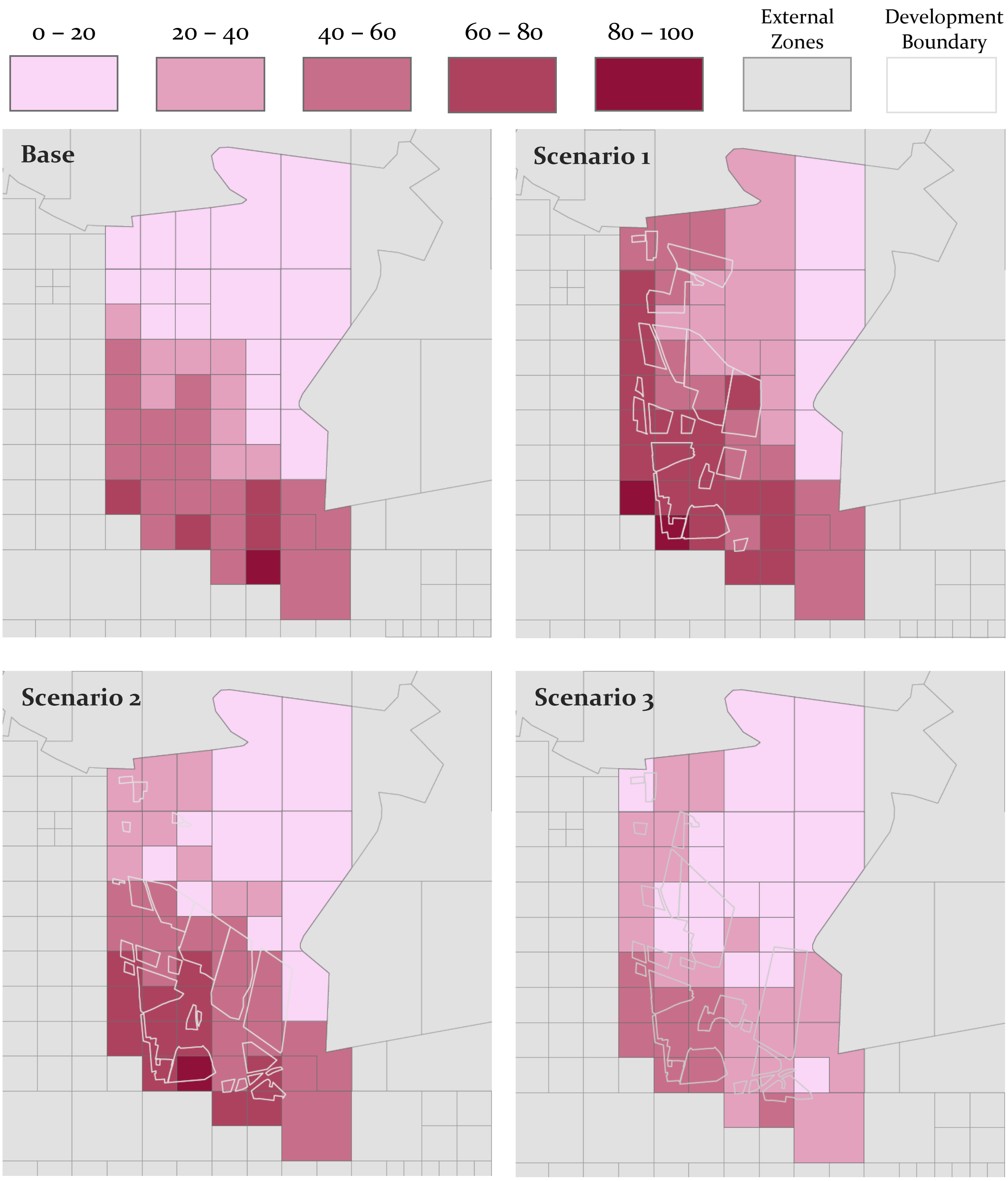



Figure 50 Northeast Munich Accessibility by Car – All Scenarios

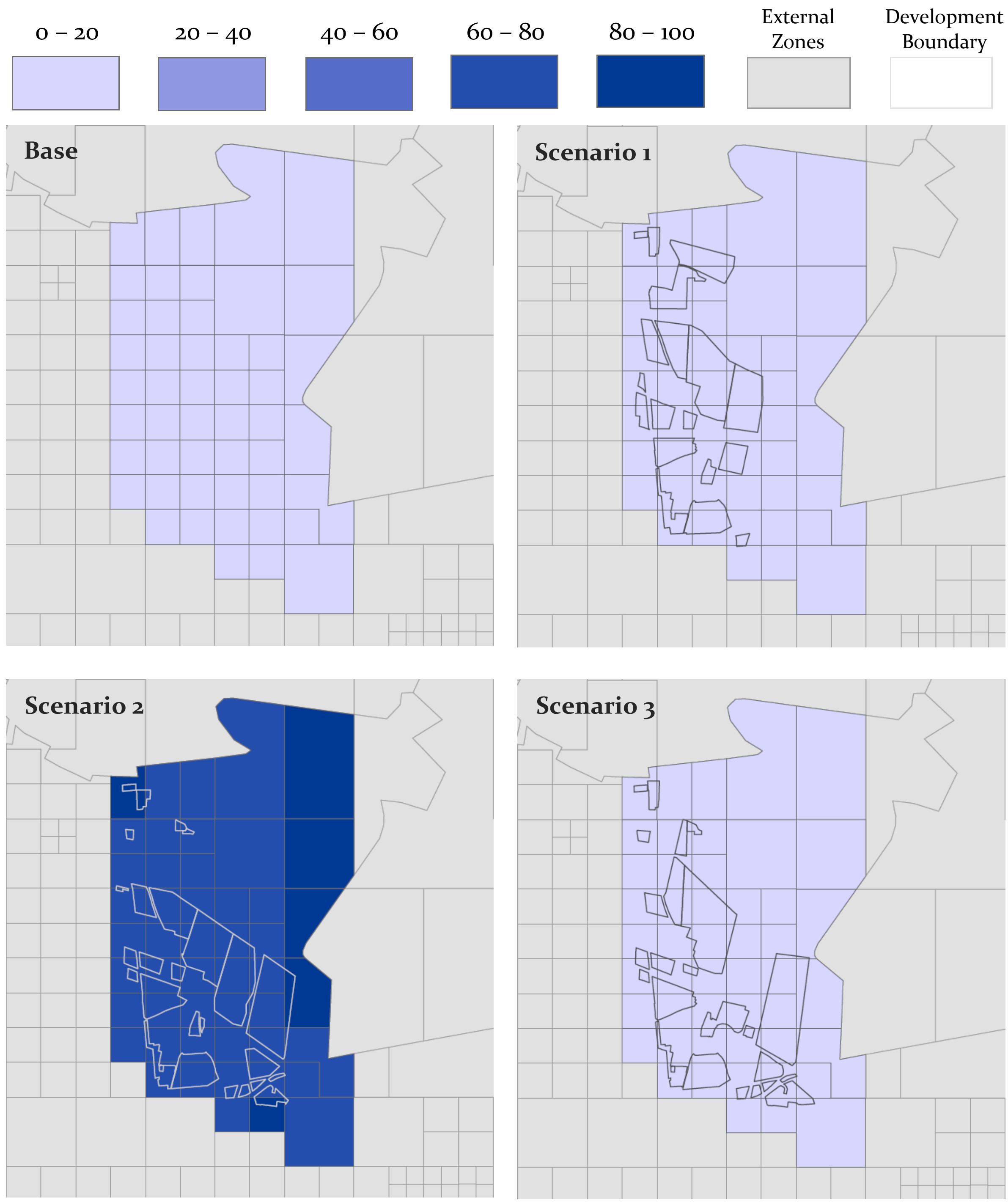



Figure 51 Northeast Munich Accessibility by Public Transport – All Scenarios

# 10 Conclusions

## 10.1 Limitations and Future Work

- First and foremost, the Munich Metropolitan Area model is a model that is currently under ongoing construction thus, is not a fully calibrated model. For this reason, the scenario results presented with this thesis should only be compared between each other and the base.
- The model uses a synthetic population that is based on microdata that has been distributed with a more aggregate dataset. This is an inevitable method to create a synthetic population to represent individuals, due to privacy matters in Germany.
- The ownership of dwellings is not modelled, ignoring households that hold a mortgage and the subsequent differences in the rental costs of the dwellings. Furthermore, the household relocation model does not know which household has a mortgage and is more likely to stay in their current dwelling.
- The allocation of land prices using the method mentioned in Chapter 7.5.1 Land Price is an approximate estimation. Shortcoming of this method is that the area of the polygons is not taken into consideration and thus nodes with significantly higher or lower land price values may be over-represented for a single raster cell. Future work includes the usage of distances to public transport and the city centre plus the triangulation method. Initially, the land price value of the node and the distance it is to public transport and the city centre should be calculated to see if there is a relationship between land price and the distances.
- Employment is estimated by mainly trusting OSM tags of polygons and points. OSM is an editable map built by volunteers therefore consistency in the content and corresponding tags are not perfect.
- Using OSM extracted area data assumes a single storey building in all cases. This may be an under-estimation of the actual number of jobs that are applicable to a certain building. Similarly, areas for POIs and buildings cover the whole proportion of land in some cases therefore over-estimating the number of jobs.
- Further research is favourable in the employment forecasting segment of the model also known as 'Firmography;' where Firmography is the modelling of firms by using variables such as industry type, location, customer size, status, structure and performance to simulate changes in workplaces.
- More work is required in forecasting the growth in the number of dwellings in the Study Area. The construction model looks at the availability of land to build new dwellings, however land availability for zones have not been refined to resemble the current state of the MMA.

- The results show a possible error in the synthetic population and synthetic jobs for the first SILO year (2011). Future work should correct overdue files.
- Accessibility values are not being calculated with each new year for with the accessibility by private transport or by public transport. The accessibility model requires future work.
- The scenarios (including the base) do not account for all proposed, planned or known future developments of the MMA Study Area, thus assuming the Northeast urban development as the only large development project in the future.
- The scenarios were compared against a base scenario that has not been calibrated or validated. Due to this the validity of the scenario analysis cannot be assumed.
- Due to the lack of information about dwelling types proposed, only an estimate could be made for the type of dwellings to be newly constructed with the scenarios.
- Similarly, all dwellings assume the same specifications such as number of bedrooms and average rent.

The above lists the limitations found with the study. Future research into these gaps will further add to the field and enhance the integrated modelling suite from where it is currently at.

## 10.2 Concluding Remarks

This thesis endeavoured to forecast the anticipated land use and transport effects with the Northeast urban development, acknowledging the permanency of such establishments once constructed. Three scenarios had been proposed by the *Referat für Stadtplanung und Bauordnung*, ‘Department of Urban Planning and Building Regulation’ (DUPBR) from the City of Munich (CoM). Each scenario encompasses different numbers of population and job targets, development density, timeline, road system and public transport upgrades. The Munich Metropolitan Model of the integrated model of SILO and MATSim is refined for the modelling years 2011 to 2050 and used to simulate the changes.

The inputs to the disaggregate land use model SILO that were of interest were the zone system, a development timeline, construction of dwellings, refinement of land prices, employment estimates, employment forecasts and additional jobs with the development. An increase in resolution of the zone system in the Northeast is made, adding a further 18 zones to form a total of 4,942 zones. The development timeline follows the phasing proposed by the DUPBR and a multi-staged implementation is assumed at the years 2020, 2030, 2040 and 2050. Dwellings are constructed using the targeted number of populations for each scenario assuming an average of 2.1 persons per household. Land prices are estimated using information from the *Gutachterausschuss für Grundstückswerte* 'Expert Committee for Land Values' (2015). Employment estimates are made with filtered POI and building data from OSM and aggregate proportions from a group of German databases. Employment forecasts follow the *Erwerbstätigenprognose für die Landeshauptstadt München und die Planungsregion 14,* 'Employment forecast for the state capital Munich and the planning region 14' report (empirica, 2015); and finally, the number of job targets from DUPBR are used.

In the agent-based transport model of MATSim, the existing private transport networks and public transport networks for the MMA Study Area are edited to include new roads and public transport lines with the development. The private transport network mainly focuses on providing connections to the new settlement, linking to the M3 highway and the Töginger Straße Autobahn. The public transport network involves an extension of the current U-Bahn line U4, eastwards from Arabellapark, with connections to existing stations such as Riem and Messestadt West in some scenarios.

The refined model is applied to the three development scenarios proposed and the results are compared to the base scenario. As expected, an increase in population, number of dwellings and number of jobs are found with all three scenarios of the urban development showing the attractiveness of the new development. The population increase is highest in Scenario 1 which almost quadruples between the simulated years of 2011 and 2050. A higher increase of people in lower income groups is evident in all scenarios.  Scenario 1 has the highest number of new MF234 dwellings, while Scenario 3 has the most MF5plus dwellings. The dwelling occupancy is similar for all development scenarios with the maximum occupancy at 98% in the first year 2011 and then 93% in year 2039. The level of occupancy drops each time new dwellings are added; however, the occupancy increases again at a very fast pace. Dwelling occupancy with the development is lower in 2050 compared to the base suggesting a slight relieving of pressure on the current housing market. As hypothesised, the average price decreases constantly for all scenarios however has slight increases with additional dwellings. This is seen to be an unrealistic increase in price due to exogenously added price values. The number of jobs increase in all scenarios with Scenario 3 producing the most number of jobs in the Northeast.

Accessibility results for both accessibility by car and public transport are unrealistic to the point that comparisons cannot be made between the scenarios. For this reason, the change in accessibility levels with the improved transport networks could not be seen. Without the accessibility results, it is difficult to predict the more attractive concept out of the three scenarios. However, looking at land use changes alone, each scenario has its own advantages. Scenario 1 has the lowest average price, most number of total dwellings, most number of lower income persons and the largest population growth; And Scenario 3 the most number of jobs.

Overall, this thesis largely contributes to the field of LUTI modelling. The first integration of SILO and MATSim has been achieved for the Munich Metropolitan Area (MMA) and a scenario analysis has been implemented. The ability to forecast and compare different scenarios is evident and adds to the argument of the usefulness of LUTI Models in planning while adding to the conversations for the Northeast Munich urban development.

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# Appendices

## List of Appendices

# A. Scenario Conceptual Layouts

Table 1 The Scenarios in Numbers

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| **Population** | 29,055 | 30,129 | 29,773 |
| **No. of Jobs** | 7,947 | 9,374 | 10,522 |
| **Total Area (acres)** | 477 | 519 | 518 |
| **Living Area (acres)** | 209 | 237 | 235 |
| **Commercial Area (acres)** | 34 | 44 | 45 |
| **Land Use Type and Density (Proportion of Total Area)** | | | |
| **Living Loose** | 45.1% | 50.7% | 35.8% |
| **Living Dense** | 13.8% | 8.9% | 1.8% |
| **Mixed Loose** | - | - | - |
| **Mixed Dense** | 41.1% | 24.1% | 62.4% |
| **Work Loose** | - | - | - |
| **Work Dense** | 0.0% | 16.3% | 0.0% |

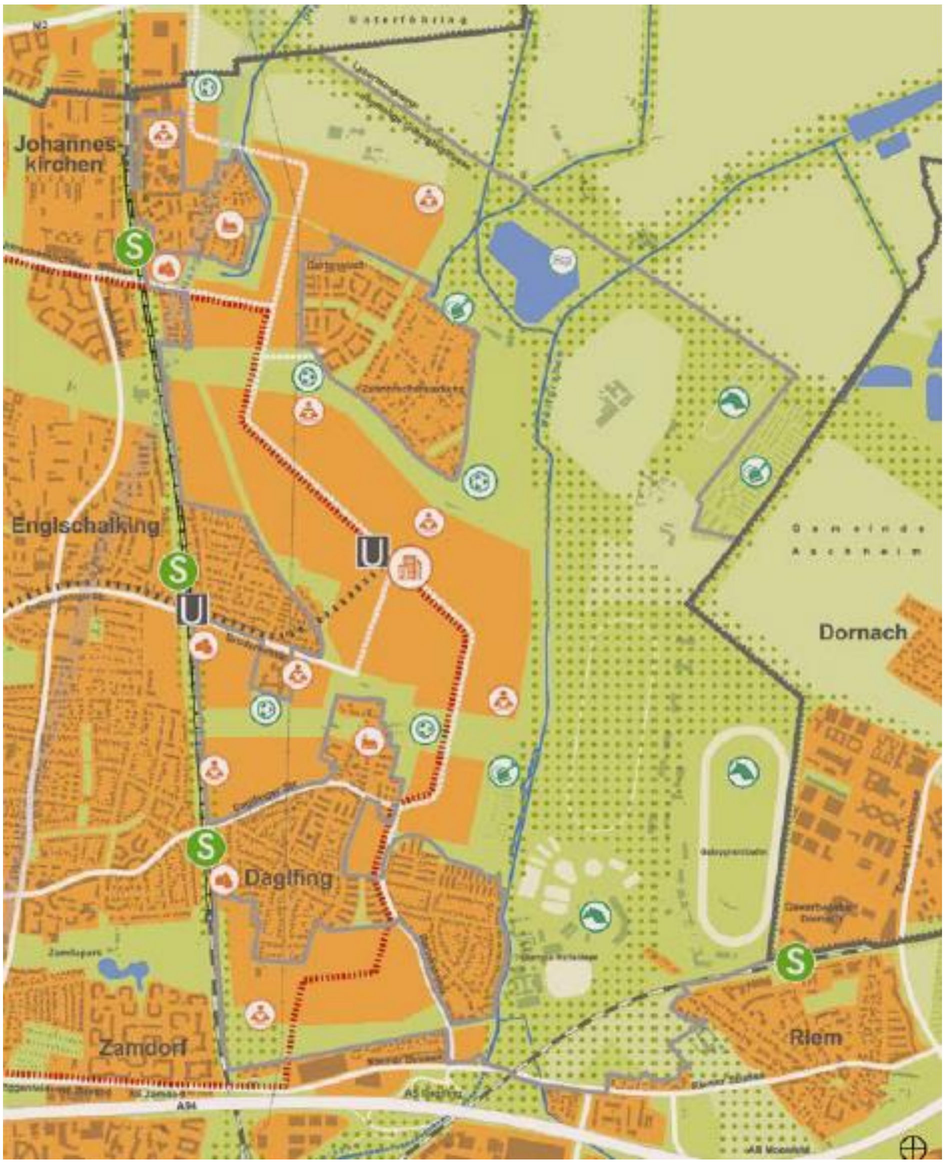


Figure 1 Conceptual Layout of Scenario 1

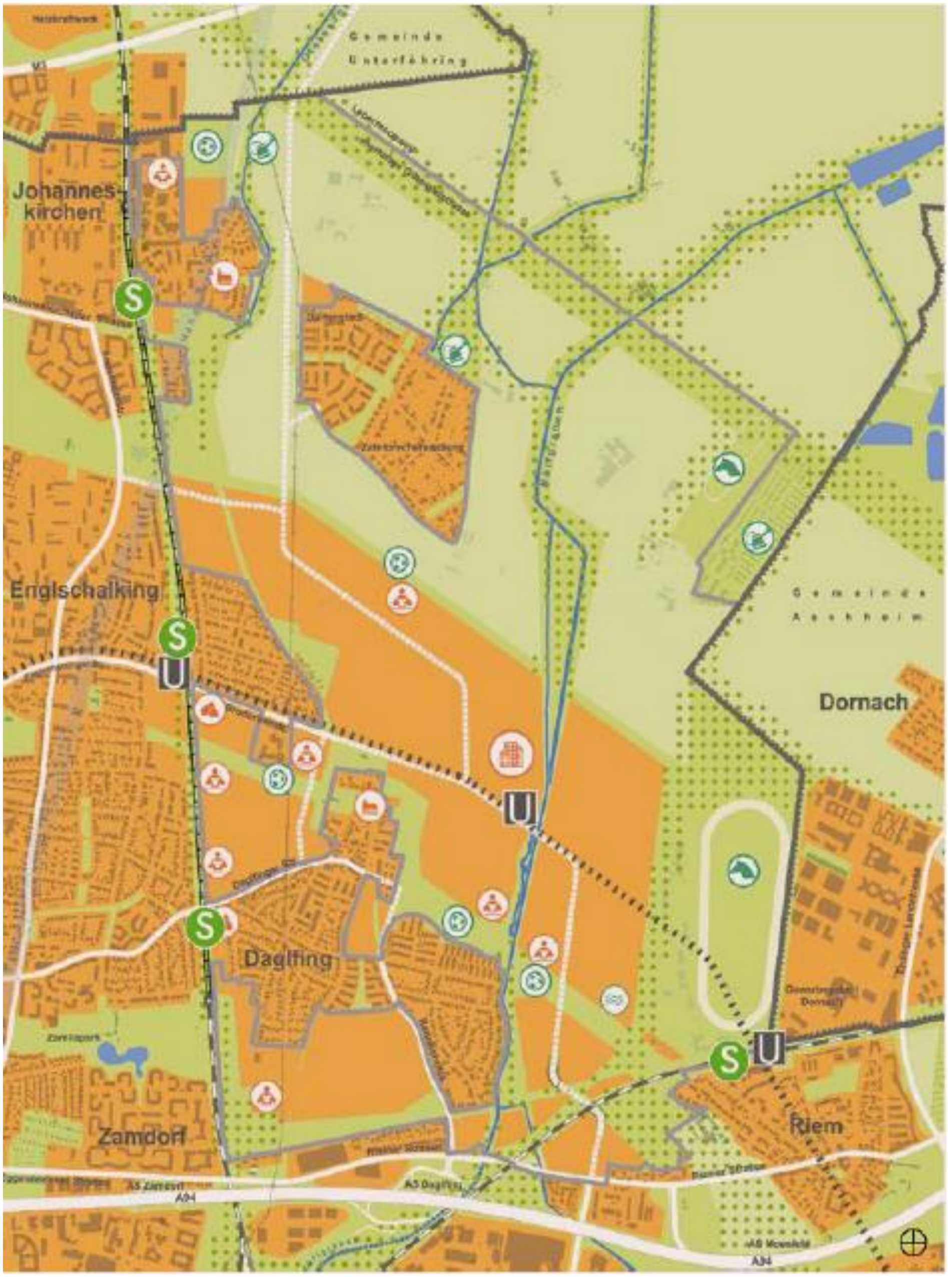


Figure 2 Conceptual Layout of Scenario 2

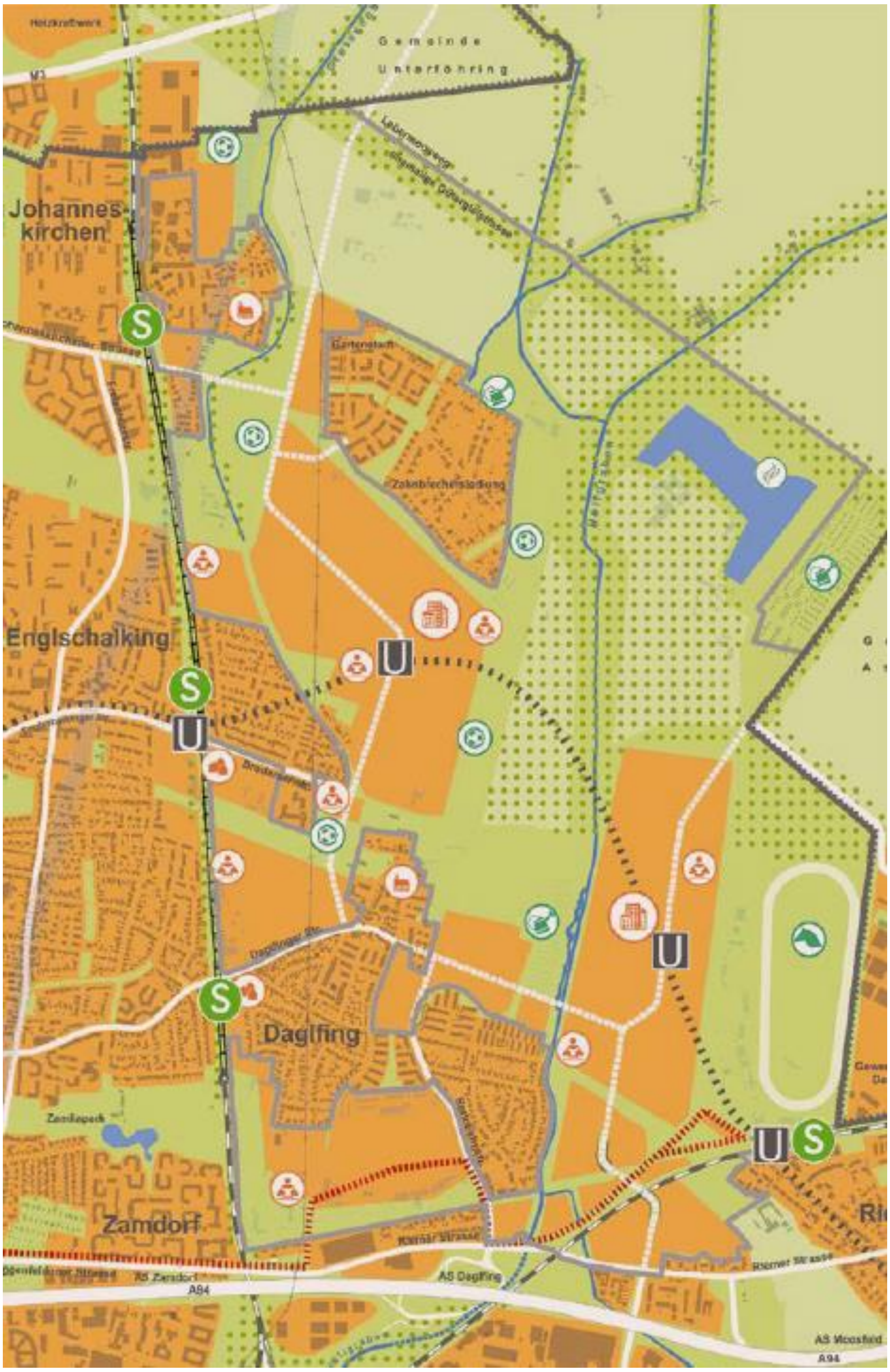


Figure 3 Conceptual Layout of Scenario 3

# B. Land Price

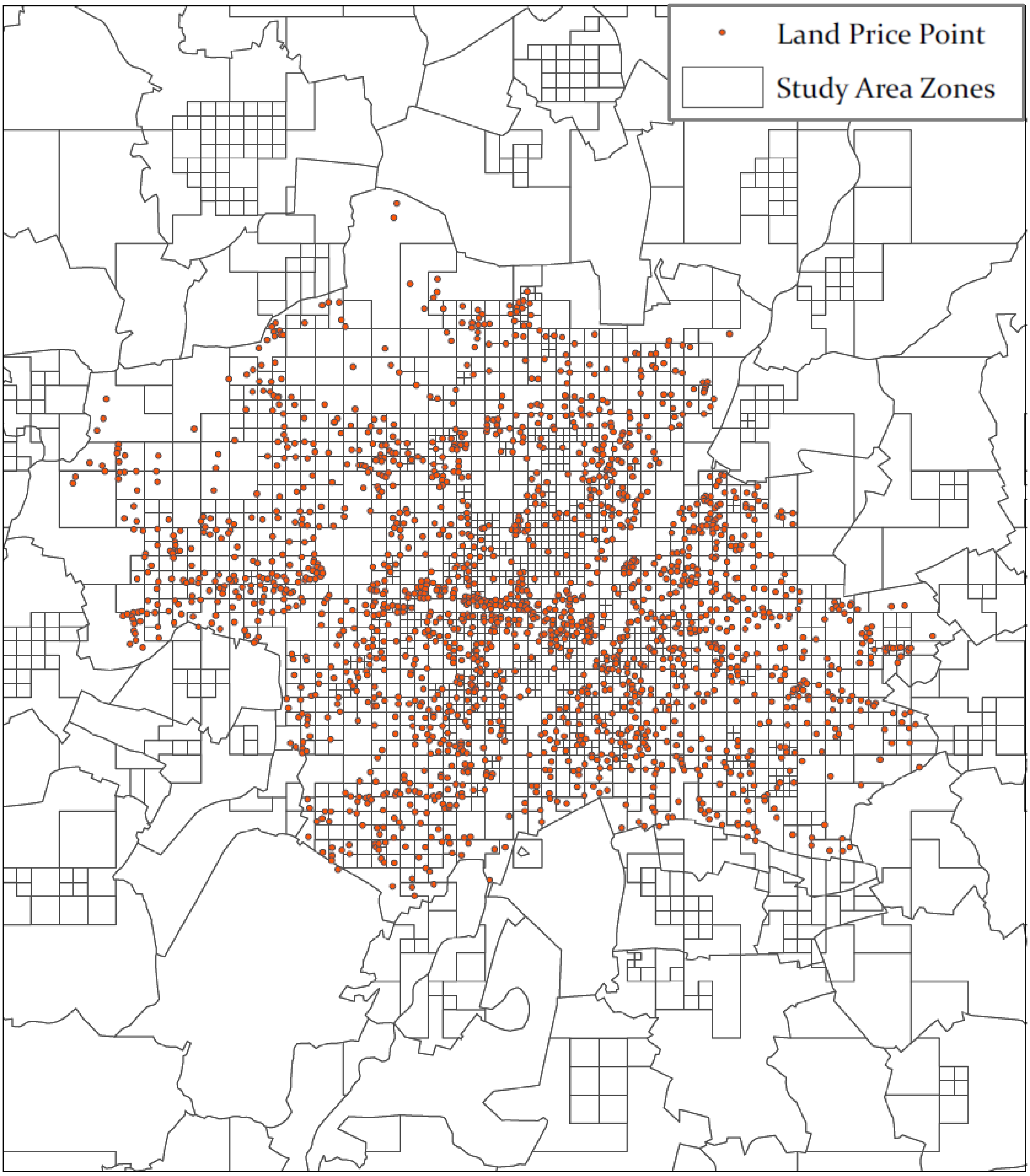


Figure 4 Land Prices Available in Munich City

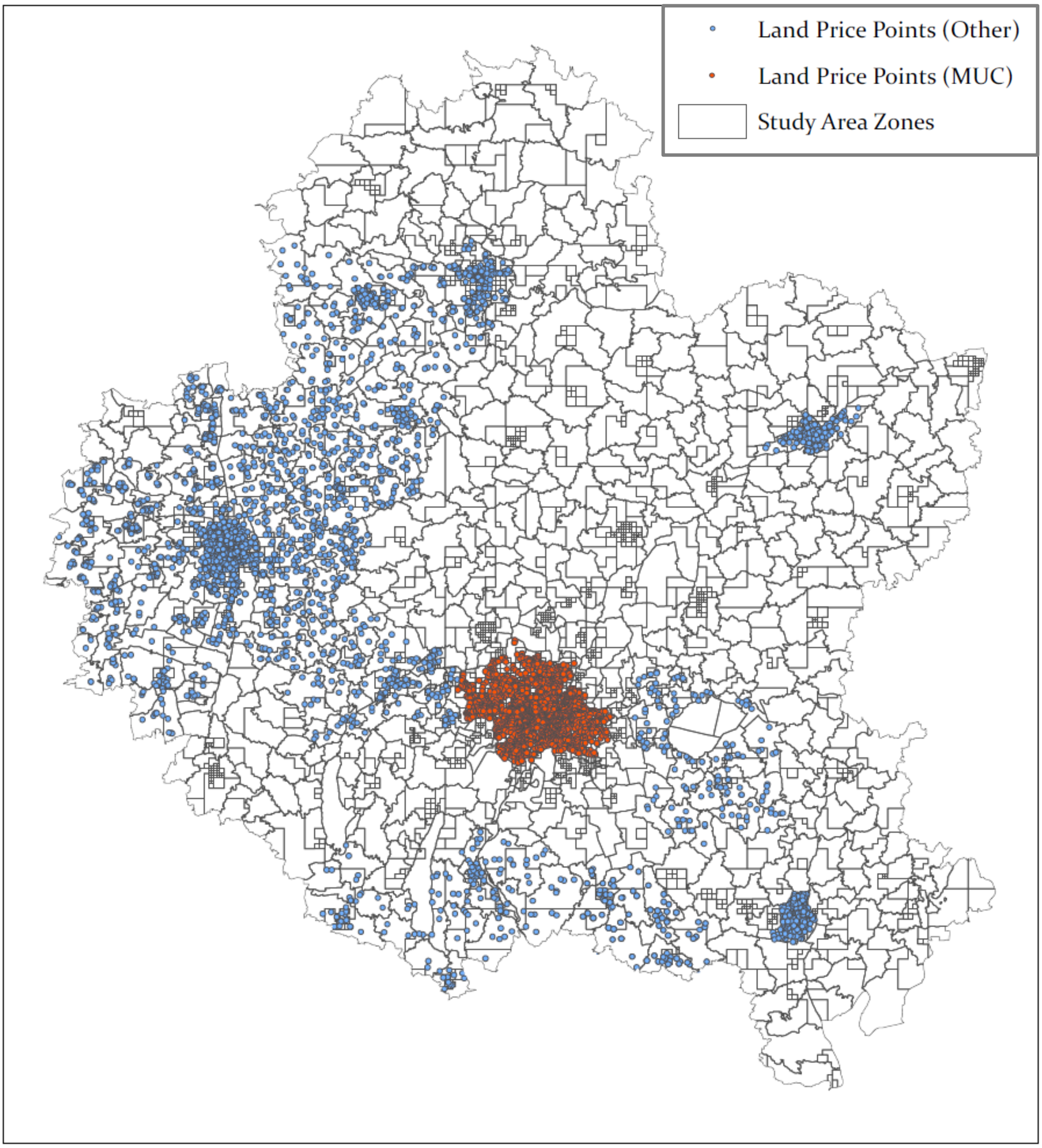


Figure 5 Land Prices Available Across the MMA

# C. Employment

## C.1 Classification of Economic Activities

Table 2 Classification of Economic Activities (recreated and translated from Statistisches Bundesamt, 2008)

| Job Number | Job Code | Job Type | Classification of Economic Activities |
|---|---|---|---|
| **job1** | Agri | Agriculture | Agriculture, forestry and fisheries |
| **job2** | Mnft | Manufacture | Mining and quarrying |
| | | | Manufacture of food products, beverages and tobacco products |
| | | | Manufacture of textiles, clothing, leather, leather goods and shoes |
| | | | Manufacture of wooden products, paper and paperboard articles thereof, manufacture of printed matter |
| | | | Cooking and mineral oil processing |
| | | | Manufacture of chemical products |
| | | | Manufacture of pharmaceutical products |
| | | | Manufacture of rubber and plastic products as well as glass and glassware, ceramics, processing of stones and earth |
| | | | Manufacture and processing of metal; metal products |
| | | | Manufacture of data-processing equipment, electronic and optical products |
| | | | Manufacture of electrical equipment |
| | | | Mechanical Engineering |
| | | | Vehicle construction |
| | | | Other manufacture of goods, repair and installation of machines and equipment |
| **job3** | Util | Utility | Power supply |
| | | | Water supply; Waste water and waste disposal and elimination of environmental pollution |
| **job4** | Cons | Construction | Building industry |
| **job5** | Retl | Retail | Trading; Maintenance and repair of motor vehicles |
| | | | Transport and storage |
| | | | Catering industry |
| **job6** | Trns | Transportation | Publishing, audio-visual and radio broadcasting |
| | | | Telecommunications |
| | | | Information technology and Information services |
| **job7** | Finc | Finance | Provision of financial services; Insurance services |
| **job8** | Rlst | Real estate | Land and housing |
| | | | Provision of freelance and technical services |
| | | | Scientific research and development |
| | | | Other self-employed, scientific and technical personnel; technical activities |

| Job Number | Job Code | Job Type | Classification of Economic Activities |
|---|---|---|---|
| | | | Other economic activities; Services |
| **job9** | Admn | Administration | Public administration, defence; Social insurance |
| **job10** | Serv | Service | Education and training |
| | | | Health care |
| | | | Homes and social services |
| | | | Arts, entertainment and recreation |
| | | | Other services |
| | | | Private households with house staff; Production of Goods and Services |
| | | | Extra-territorial organisations and bodies |

## C.2 OSM Tags and Job Type Classification

Table 3 OSM Tags and Job Type Classification for POI Points and Polygons

| | OSM Tags | POI (points) | POI (polygon) | Job Type |
|---|---|---|---|---|
| **1** | alpine_hut | 1 | 13 | 0 |
| **2** | archaeological | 152 | 116 | 0 |
| **3** | arts_centre | 59 | 41 | 10 |
| **4** | artwork | 299 | 38 | 0 |
| **5** | atm | 524 | 7 | 0 |
| **6** | attraction | 284 | 400 | 0 |
| **7** | bakery | 1710 | 248 | 5 |
| **8** | bank | 1233 | 297 | 7 |
| **9** | bar | 409 | 44 | 5 |
| **10** | battlefield | 3 | | 0 |
| **11** | beauty_shop | 249 | 39 | 5 |
| **12** | bench | 12266 | 18 | 0 |
| **13** | beverages | 477 | 196 | 5 |
| **14** | bicycle_rental | 125 | 17 | 10 |
| **15** | bicycle_shop | 356 | 69 | 5 |
| **16** | biergarten | 304 | 321 | 5 |
| **17** | bookshop | 208 | 38 | 5 |
| **18** | butcher | 681 | 156 | 5 |
| **19** | cafe | 1357 | 198 | 5 |
| **20** | camera_surveillance | 594 | 11 | 0 |
| **21** | camp_site | 10 | 133 | 0 |
| **22** | car_dealership | 437 | 459 | 10 |
| **23** | car_rental | 100 | 24 | 10 |
| **24** | car_sharing | 171 | 22 | 0 |
| **25** | car_wash | 187 | 178 | 10 |
| **26** | caravan_site | 20 | 30 | 0 |
| **27** | castle | 63 | 166 | 0 |
| **28** | chalet | 10 | 14 | 0 |
| **29** | chemist | 265 | 83 | 5 |
| **30** | cinema | 75 | 16 | 5 |
| **31** | clothes | 1273 | 501 | 5 |
| **32** | college | 14 | 28 | 10 |
| **33** | comms_tower | 173 | 21 | 6 |
| **34** | community_centre | 103 | 162 | 10 |
| **35** | computer_shop | 104 | 10 | 5 |
| **36** | convenience | 403 | 63 | 5 |
| **37** | courthouse | 13 | 51 | 9 |
| **38** | dentist | 473 | 20 | 10 |

| | OSM Tags | POI (points) | POI (polygon) | Job Type |
|---|---|---|---|---|
| **39** | department_store | 38 | 31 | 5 |
| **40** | doctors | 1230 | 84 | 10 |
| **41** | dog_park | 5 | 21 | 0 |
| **42** | doityourself | 195 | 177 | 5 |
| **43** | drinking_water | 218 | 1 | 0 |
| **44** | embassy | 31 | 8 | 9 |
| **45** | fast_food | 1029 | 356 | 5 |
| **46** | fire_station | 493 | 620 | 10 |
| **47** | florist | 410 | 80 | 5 |
| **48** | food_court | 2 | 12 | 5 |
| **49** | fountain | 577 | 169 | 0 |
| **50** | furniture_shop | 232 | 126 | 5 |
| **51** | garden_centre | 80 | 98 | 5 |
| **52** | gift_shop | 82 | 13 | 5 |
| **53** | golf_course | 2 | 292 | 10 |
| **54** | graveyard | 6 | 1353 | 0 |
| **55** | greengrocer | 185 | 28 | 5 |
| **56** | guesthouse | 231 | 152 | 5 |
| **57** | hairdresser | 1499 | 106 | 10 |
| **58** | hospital | 48 | 318 | 10 |
| **59** | hostel | 29 | 31 | 5 |
| **60** | hotel | 731 | 486 | 5 |
| **61** | hunting_stand | 2261 | 3 | 0 |
| **62** | ice_rink | 2 | 9 | 10 |
| **63** | jeweller | 291 | 52 | 5 |
| **64** | kindergarten | 773 | 1384 | 10 |
| **65** | kiosk | 337 | 140 | 5 |
| **66** | laundry | 251 | 30 | 10 |
| **67** | library | 138 | 73 | 10 |
| **68** | lighthouse | 2 | 0 | 0 |
| **69** | mall | 6 | 152 | 5 |
| **70** | memorial | 786 | 68 | 0 |
| **71** | mobile_phone_shop | 150 | 48 | 5 |
| **72** | monument | 34 | 23 | 0 |
| **73** | motel | 9 | 9 | 5 |
| **74** | museum | 142 | 178 | 10 |
| **75** | newsagent | 52 | 18 | 5 |
| **76** | nightclub | 105 | 23 | 10 |
| **77** | nursing_home | 35 | 136 | 10 |
| **78** | observation_tower | 5 | 10 | 10 |
| **79** | optician | 353 | 40 | 10 |

| | OSM Tags | POI (points) | POI (polygon) | Job Type |
|---|---|---|---|---|
| **80** | outdoor_shop | 40 | 7 | 5 |
| **81** | park | 11 | 5022 | 0 |
| **82** | pharmacy | 956 | 82 | 5 |
| **83** | picnic_site | 431 | 21 | 0 |
| **84** | pitch | 206 | 9758 | 0 |
| **85** | playground | 1818 | 3311 | 0 |
| **86** | police | 58 | 107 | 10 |
| **87** | post_box | 3520 | 3 | 0 |
| **88** | post_office | 407 | 51 | 5 |
| **89** | prison | | 44 | 10 |
| **90** | pub | 689 | 91 | 5 |
| **91** | public_building | 125 | 452 | 10 |
| **92** | recycling | 1156 | 236 | 0 |
| **93** | recycling_clothes | 529 | 1 | 0 |
| **94** | recycling_glass | 1383 | 152 | 0 |
| **95** | recycling_metal | 13 | 3 | 0 |
| **96** | recycling_paper | 192 | 12 | 0 |
| **97** | restaurant | 4367 | 1216 | 5 |
| **98** | ruins | 76 | 55 | 0 |
| **99** | school | 381 | 3415 | 10 |
| **100** | shelter | 273 | 2604 | 0 |
| **101** | shoe_shop | 341 | 127 | 5 |
| **102** | sports_centre | 335 | 3026 | 10 |
| **103** | sports_shop | 147 | 66 | 5 |
| **104** | stadium | 4 | 257 | 10 |
| **105** | stationery | 195 | 43 | 5 |
| **106** | supermarket | 1207 | 864 | 5 |
| **107** | swimming_pool | 42 | 2334 | 10 |
| **108** | telephone | 1383 | 3 | 0 |
| **109** | theatre | 61 | 70 | 10 |
| **110** | theme_park | 5 | 7 | 10 |
| **111** | toilet | 508 | 224 | 0 |
| **112** | tourist_info | 3906 | 52 | 10 |
| **113** | tower | 179 | 387 | 0 |
| **114** | town_hall | 147 | 256 | 9 |
| **115** | toy_shop | 101 | 29 | 5 |
| **116** | track | 2 | 686 | 0 |
| **117** | travel_agent | 230 | 32 | 10 |
| **118** | university | 15 | 463 | 10 |
| **119** | vending_any | 2729 | 6 | 0 |
| **120** | vending_cigarette | 695 | 0 | 0 |

| | OSM Tags | POI (points) | POI (polygon) | Job Type |
|---|---|---|---|---|
| **121** | vending_machine | 71 | 0 | 0 |
| **122** | vending_parking | 597 | 0 | 0 |
| **123** | veterinary | 206 | 31 | 10 |
| **124** | video_shop | 46 | 6 | 5 |
| **125** | viewpoint | 425 | 28 | 0 |
| **126** | waste_basket | 1947 | 2 | 0 |
| **127** | wastewater_plant | 31 | 492 | 3 |
| **128** | water_mill | 30 | 17 | 0 |
| **129** | water_tower | 34 | 42 | 0 |
| **130** | water_well | 81 | 36 | 0 |
| **131** | water_works | 40 | 101 | 3 |
| **132** | wayside_cross | 3874 | 3 | 0 |
| **133** | wayside_shrine | 577 | 39 | 0 |
| **134** | windmill | 2 | 0 | 0 |
| **135** | zoo | 1 | 206 | 10 |
| | Total | 75095 | 47784 | 0 |

Table 4 OSM Tags and Job Type Classification for Building Polygons

| | OSM Tags | Buildings (polygon) | Job Type |
|---|---|---|---|
| **1** | abandoned | 28 | 0 |
| **2** | appartments | 40 | 0 |
| **3** | Asylunterkunft | 30 | 0 |
| **4** | attachment | 173 | 0 |
| **5** | barn | 6934 | 1 |
| **6** | basin | 4 | 0 |
| **7** | bicycle_parking | 7 | 0 |
| **8** | Bing | 12 | 0 |
| **9** | boat | 1 | 0 |
| **10** | Bootshaus FKL | 257 | 0 |
| **11** | brewery | 192 | 2 |
| **12** | bridge | 212 | 0 |
| **13** | brothel | 6 | 0 |
| **14** | bunker_silo | 3 | 0 |
| **15** | butcher | 3 | 5 |
| **16** | car_port | 12 | 0 |
| **17** | Carport | 9 | 0 |
| **18** | castle | 2 | 0 |
| **19** | cathedral | 471 | 10 |
| **20** | chalet | 1 | 0 |
| **21** | chapel | 5088 | 10 |

| | OSM Tags | Buildings (polygon) | Job Type |
|---|---|---|---|
| **22** | chicken_coop | 1 | 1 |
| **23** | chimney | 6 | 0 |
| **24** | church | 43920 | 10 |
| **25** | Cinema | 36 | 5 |
| **26** | city_wall | 2 | 0 |
| **27** | civic | 4372 | 10 |
| **28** | club_house | 27 | 5 |
| **29** | college | 55 | 10 |
| **30** | commercial | 39670 | 5 |
| **31** | construction | 15155 | 0 |
| **32** | container | 171 | 0 |
| **33** | cot | 5 | 0 |
| **34** | cowshed | 197 | 1 |
| **35** | demolised | 8 | 0 |
| **36** | depot | 28 | 6 |
| **37** | Designhalle | 12 | 0 |
| **38** | det | 16 | 0 |
| **39** | digester | 16 | 3 |
| **40** | disused | 53 | 0 |
| **41** | elevator | 8 | 0 |
| **42** | entrance | 86 | 0 |
| **43** | farm | 6397 | 1 |
| **44** | farm_auxiliary | 2842 | 1 |
| **45** | farmhouse | 1 | 0 |
| **46** | farmyard | 5 | 1 |
| **47** | fire_station | 4 | 10 |
| **48** | fixme | 8 | 0 |
| **49** | gara | 61 | 0 |
| **50** | garage;house | 2 | 0 |
| **51** | garage;shed | 27 | 0 |
| **52** | garage_entrance | 166 | 0 |
| **53** | garas | 74 | 0 |
| **54** | garden | 9 | 0 |
| **55** | gerätestadel | 1 | 0 |
| **56** | glasshouse | 67 | 0 |
| **57** | granary | 158 | 0 |
| **58** | grandstand | 102 | 5 |
| **59** | greenhouse | 10276 | 1 |
| **60** | greeny | 10 | 0 |
| **61** | grill shed | 83 | 0 |
| **62** | grocery_store | 1 | 5 |

| | OSM Tags | Buildings (polygon) | Job Type |
|---|---|---|---|
| **63** | hall | 1 | 10 |
| **64** | hangar | 425 | 5 |
| **65** | Haupteingang | 10 | 0 |
| **66** | henhouse | 2 | 1 |
| **67** | hospital | 119 | 10 |
| **68** | hotel | 1315 | 5 |
| **69** | house;yes | 159 | 0 |
| **70** | indoor_riding_arena | 1 | 10 |
| **71** | industrial | 17221 | 2 |
| **72** | kindergarten | 666 | 10 |
| **73** | leerstehend | 33 | 0 |
| **74** | library | 15 | 10 |
| **75** | logistics | 20 | 6 |
| **76** | manufacture | 2299 | 2 |
| **77** | monastery | 136 | 10 |
| **78** | mortuary | 2 | 0 |
| **79** | mosque | 96 | 10 |
| **80** | Mosthaus | 3 | 0 |
| **81** | Multifunktionshalle | 12 | 10 |
| **82** | multi-storey | 1 | 0 |
| **83** | music_school | 4 | 10 |
| **84** | nein | 5 | 0 |
| **85** | new | 840 | 0 |
| **86** | Offenstall | 1 | 0 |
| **87** | office | 8311 | 10 |
| **88** | offices | 1 | 10 |
| **89** | parking | 75 | 0 |
| **90** | part | 14 | 0 |
| **91** | pavilion | 133 | 10 |
| **92** | Pferdestall | 2 | 10 |
| **93** | place_of_worship | 6 | 10 |
| **94** | pole | 5 | 0 |
| **95** | power_station | 1 | 3 |
| **96** | prefabricated | 160 | 0 |
| **97** | private | 7 | 0 |
| **98** | proposed | 99 | 0 |
| **99** | public | 7548 | 10 |
| **100** | public_building | 24 | 10 |
| **101** | radome | 9 | 0 |
| **102** | residential / garage | 1 | 0 |
| **103** | retail | 7616 | 5 |

| | OSM Tags | Buildings (polygon) | Job Type |
|---|---|---|---|
| **104** | retirement_home | 72 | 0 |
| **105** | riding_hall | 2 | 10 |
| **106** | riding_school | 6 | 10 |
| **107** | roof | 62968 | 0 |
| **108** | roof;industrial | 2 | 0 |
| **109** | roofed ramp | 3 | 0 |
| **110** | root | 43 | 0 |
| **111** | ruins | 82 | 0 |
| **112** | school | 10496 | 10 |
| **113** | Schöplergasse | 514 | 0 |
| **114** | Schuppen | 83 | 0 |
| **115** | semi-detached | 12 | 0 |
| **116** | service | 1545 | 10 |
| **117** | shelder | 14 | 0 |
| **118** | shelter | 397 | 0 |
| **119** | sheltershelter | 6 | 0 |
| **120** | shop | 56 | 5 |
| **121** | sight | 26 | 0 |
| **122** | silage | 3 | 0 |
| **123** | silo | 276 | 0 |
| **124** | slurry_tank | 18 | 0 |
| **125** | sport | 1 | 10 |
| **126** | Sporthalle | 38 | 10 |
| **127** | sports_centre | 1 | 10 |
| **128** | sports_hall | 27 | 10 |
| **129** | Stab,_Unterkunft,_Le | 3 | 0 |
| **130** | stable | 485 | 1 |
| **131** | stadium | 1 | 10 |
| **132** | static_caravan | 60 | 0 |
| **133** | storage | 1 | 0 |
| **134** | storage_tank | 109 | 0 |
| **135** | store | 1 | 0 |
| **136** | substation | 460 | 3 |
| **137** | supermarket | 383 | 5 |
| **138** | synagogue | 81 | 10 |
| **139** | tech_cab | 1 | 0 |
| **140** | temple | 162 | 10 |
| **141** | tent | 10 | 0 |
| **142** | THW | 22 | 0 |
| **143** | tower | 1444 | 0 |
| **144** | townhall | 15 | 9 |

| | OSM Tags | Buildings (polygon) | Job Type |
|---|---|---|---|
| **145** | train_station | 1616 | 6 |
| **146** | transformer_tower | 1410 | 3 |
| **147** | transportation | 227 | 6 |
| **148** | Truppenküche | 3 | 0 |
| **149** | TV shed | 83 | 0 |
| **150** | Unbekannt | 1 | 0 |
| **151** | university | 2585 | 10 |
| **152** | utility | 333 | 3 |
| **153** | Verein | 1 | 0 |
| **154** | Vereinsheim | 16 | 0 |
| **155** | vicarage | 23 | 0 |
| **156** | warehouse | 4313 | 5 |
| **157** | waste | 14 | 0 |
| **158** | waste_disposal | 54 | 0 |
| **159** | wayside_chapel | 8 | 0 |
| **160** | wayside_cross | 17 | 0 |
| **161** | wayside_shrine | 5 | 0 |
| **162** | Wohngebäude | 20 | 0 |
| **163** | workshop | 74 | 2 |
| **164** | yes;construction | 31 | 0 |
| **165** | yes;house | 123 | 0 |
| **166** | yes;industrial | 69 | 2 |
| | (blank) | 401699 | |
| | Total | 677675 | |

Table 5 OSM Tags and Job Type Classification for Land Use Polygons

| | OSM Tags | Land Use (polygon) | Job Type |
|---|---|---|---|
| **1** | allotments | 1025 | 0 |
| **2** | cemetery | 1024 | 0 |
| **3** | commercial | 1375 | 5 |
| **4** | farm | 42624 | 1 |
| **5** | forest | 24804 | 0 |
| **6** | grass | 11374 | 0 |
| **7** | heath | 232 | 0 |
| **8** | industrial | 2251 | 2 |
| **9** | meadow | 29997 | 0 |
| **10** | military | 66 | 10 |
| **11** | nature_reserve | 111 | 0 |
| **12** | orchard | 479 | 1 |
| **13** | park | 2087 | 0 |

| | OSM Tags | Land Use (polygon) | Job Type |
|---|---|---|---|
| **14** | quarry | 870 | 2 |
| **15** | recreation_ground | 430 | 10 |
| **16** | residential | 12238 | 0 |
| **17** | retail | 367 | 5 |
| **18** | scrub | 20388 | 0 |
| **19** | vineyard | 10 | 0 |
| | Total | 151752 | |

Table 6 Percentage of Area Dedicated to Each Job Type in the Northeast

| Job Number | Job Code | Percentage of Area Dedicated to Each Job Type (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0 | N/A | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 1 | Agri | 10.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | Mnft | 0.1 | 55.2 | 1.5 | 7.9 | 2.7 | 7.4 | 0.4 | 8.1 | 0.8 | 16.0 |
| 3 | Util | 1.2 | 34.7 | 3.9 | 10.9 | 5.2 | 12.3 | 0.9 | 9.9 | 1.6 | 19.5 |
| 4 | Cons | 1.0 | 38.6 | 2.9 | 13.2 | 5.4 | 9.4 | 1.0 | 8.3 | 1.5 | 18.8 |
| 5 | Retl | 0.0 | 0.7 | 0.0 | 0.1 | 48.5 | 1.8 | 2.5 | 16.7 | 4.1 | 25.6 |
| 6 | Trns | 0.0 | 25.9 | 1.7 | 6.8 | 1.7 | 21.2 | 0.3 | 16.1 | 0.6 | 25.6 |
| 7 | Finc | 1.6 | 1.5 | 0.1 | 0.5 | 33.0 | 6.6 | 15.6 | 19.6 | 8.4 | 13.1 |
| 8 | Rlst | 0.0 | 0.9 | 0.0 | 0.3 | 37.9 | 2.2 | 3.3 | 26.6 | 1.5 | 27.2 |
| 9 | Admn | 0.1 | 1.5 | 0.1 | 0.4 | 17.5 | 6.9 | 0.7 | 11.1 | 30.1 | 31.7 |
| 10 | Serv | 0.0 | 0.3 | 0.0 | 0.1 | 34.4 | 0.7 | 0.1 | 2.7 | 11.8 | 50.0 |

## C.3 Employment Forecast

Table 7 Employment Forecast of the Munich Region (recreated using data from '*Tabelle 2: Entwicklung der Erwerbstätigen nach Wirtschaftsklassifikation in den Kreisen der Reion München, 2000-2030,*' empirica, 2015)

| Job Classification (empirica, 2015) | Forecasts | Year | No. of jobs (absolute) | % change in no. of jobs | % change in no. of jobs per year |
|---|---|---|---|---|---|
| **A** | Base | 2013 | 13268 | - | - |
| | Negativ | 2030 | 7432 | -44.0% | -2.59% |
| | Basis | 2030 | 8151 | -38.6% | -2.27% |
| | Trend | 2030 | 9579 | -27.8% | -1.64% |
| **B to E** | Base | 2013 | 217030 | - | - |
| | Negativ | 2030 | 196234 | -9.6% | -0.56% |
| | Basis | 2030 | 237643 | 9.5% | 0.56% |
| | Trend | 2030 | 203297 | -6.3% | -0.37% |
| **F** | Base | 2013 | 70349 | - | - |
| | Negativ | 2030 | 75899 | 7.9% | 0.46% |
| | Basis | 2030 | 82536 | 17.3% | 1.02% |
| | Trend | 2030 | 80117 | 13.9% | 0.82% |
| **G to J** | Base | 2013 | 515938 | - | - |
| | Negativ | 2030 | 537528 | 4.2% | 0.25% |
| | Basis | 2030 | 550372 | 6.7% | 0.39% |
| | Trend | 2030 | 602199 | 16.7% | 0.98% |
| **K to N** | Base | 2013 | 426157 | - | - |
| | Negativ | 2030 | 418833 | -1.7% | -0.10% |
| | Basis | 2030 | 444872 | 4.4% | 0.26% |
| | Trend | 2030 | 558694 | 31.1% | 1.83% |
| **O to T** | | 2013 | 497234 | - | - |
| | Negativ | 2030 | 534804 | 7.6% | 0.44% |
| | Basis | 2030 | 564492 | 13.5% | 0.80% |
| | Trend | 2030 | 570309 | 14.7% | 0.86% |
| **Total Employment** | Base | 2013 | 1739976 | - | - |
| | Negativ | 2030 | 1770731 | 1.8% | 0.10% |
| | Basis | 2030 | 1888065 | 8.5% | 0.50% |
| | Trend | 2030 | 2024194 | 16.3% | 0.96% |

Table 8 Northeast Munich Job Code x Job Classification with Description

| Job Number | Job Code | Job Classification (empirica, 2015) | Job Description (empirica, 2015) |
|---|---|---|---|
| **job1** | Agri | A | Agriculture and forestry, fisheries |
| **job2** | Mnft | B to E | Production industry |
| **job3** | Util | | |
| **job4** | Cons | F | Construction |
| **job5** | Retl | G to J | Trade, transport, tourism, information and communication |
| **job6** | Trns | | |
| **job7** | Finc | K to N | Financial, insurance, company services, land, real estate |
| **job8** | Rlst | | |
| **job9** | Admn | O to T | Public and other service providers, education, health |
| **job10** | Serv | | |

## C.4 Employment Scenarios

Table 9 Total Number of Jobs in the Northeast Area by Job Type per Forecast Year – Scenario Base

| | job1 | job2 | job3 | job4 | job5 | job6 | job7 | job8 | job9 | job10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **2011** | 53 | 17 | 2 | 6 | 578 | 104 | 166 | 502 | 192 | 666 |
| **2019** | 46 | 16 | 2 | 6 | 624 | 112 | 192 | 579 | 207 | 717 |
| **2020** | 45 | 16 | 2 | 6 | 630 | 113 | 195 | 589 | 208 | 723 |
| **2029** | 38 | 16 | 2 | 7 | 682 | 123 | 223 | 675 | 224 | 776 |
| **2030** | 37 | 16 | 2 | 7 | 688 | 124 | 227 | 684 | 225 | 782 |
| **2039** | 30 | 16 | 2 | 7 | 713 | 128 | 232 | 700 | 242 | 840 |
| **2040** | 29 | 17 | 2 | 8 | 716 | 129 | 232 | 702 | 244 | 847 |
| **2049** | 24 | 17 | 2 | 8 | 741 | 133 | 238 | 719 | 262 | 909 |
| **2050** | 23 | 17 | 2 | 8 | 744 | 134 | 239 | 720 | 264 | 916 |

Table 10 Total Number of Jobs in the Northeast Area by Job Type per Forecast Year – Scenario 1

| | job1 | job2 | job3 | job4 | job5 | job6 | job7 | job8 | job9 | job10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **2011** | 53 | 17 | 2 | 6 | 578 | 104 | 166 | 502 | 192 | 666 |
| **2019** | 46 | 16 | 2 | 6 | 624 | 112 | 192 | 579 | 207 | 717 |
| **2020** | 54 | 66 | 7 | 21 | 752 | 175 | 217 | 672 | 253 | 887 |
| **2029** | 45 | 64 | 7 | 23 | 814 | 189 | 249 | 771 | 272 | 952 |
| **2030** | 50 | 295 | 32 | 94 | 1646 | 528 | 494 | 1592 | 565 | 2011 |
| **2039** | 40 | 310 | 33 | 103 | 1705 | 547 | 505 | 1629 | 607 | 2159 |
| **2040** | 43 | 442 | 47 | 144 | 2172 | 737 | 641 | 2085 | 774 | 2763 |
| **2049** | 35 | 464 | 49 | 158 | 2250 | 764 | 656 | 2134 | 831 | 2968 |
| **2050** | 35 | 531 | 56 | 179 | 2485 | 859 | 724 | 2362 | 918 | 3280 |

Table 11 Total Number of Jobs in the Northeast Area by Job Type per Forecast Year – Scenario 2

| | job1 | job2 | job3 | job4 | job5 | job6 | job7 | job8 | job9 | job10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **2011** | 53 | 17 | 2 | 6 | 578 | 104 | 166 | 502 | 192 | 666 |
| **2019** | 46 | 16 | 2 | 6 | 624 | 112 | 192 | 579 | 207 | 717 |
| **2020** | 46 | 57 | 6 | 19 | 774 | 172 | 237 | 730 | 259 | 906 |
| **2029** | 39 | 55 | 6 | 20 | 838 | 186 | 272 | 836 | 278 | 973 |
| **2030** | 46 | 393 | 42 | 125 | 2049 | 680 | 628 | 2031 | 705 | 2515 |
| **2039** | 37 | 413 | 44 | 137 | 2123 | 704 | 643 | 2079 | 757 | 2701 |
| **2040** | 39 | 516 | 55 | 169 | 2488 | 853 | 749 | 2434 | 889 | 3177 |
| **2049** | 32 | 542 | 58 | 185 | 2577 | 884 | 766 | 2491 | 955 | 3412 |
| **2050** | 33 | 625 | 66 | 211 | 2871 | 1003 | 851 | 2776 | 1062 | 3800 |

Table 12 Total Number of Jobs in the Northeast Area by Job Type per Forecast Year – Scenario 3

| | job1 | job2 | job3 | job4 | job5 | job6 | job7 | job8 | job9 | job10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **2011** | 53 | 17 | 2 | 6 | 578 | 104 | 166 | 502 | 192 | 666 |
| **2019** | 46 | 16 | 2 | 6 | 624 | 112 | 192 | 579 | 207 | 717 |
| **2020** | 47 | 73 | 8 | 24 | 832 | 196 | 254 | 787 | 280 | 981 |
| **2029** | 39 | 71 | 8 | 26 | 901 | 212 | 291 | 902 | 300 | 1053 |
| **2030** | 45 | 351 | 37 | 112 | 1908 | 622 | 587 | 1896 | 655 | 2334 |
| **2039** | 36 | 369 | 39 | 123 | 1976 | 644 | 601 | 1940 | 703 | 2506 |
| **2040** | 41 | 599 | 64 | 194 | 2792 | 977 | 839 | 2739 | 994 | 3556 |
| **2049** | 33 | 629 | 67 | 213 | 2893 | 1012 | 859 | 2803 | 1068 | 3819 |
| **2050** | 34 | 695 | 74 | 234 | 3126 | 1107 | 926 | 3029 | 1155 | 4133 |

# D. Private Transport Network

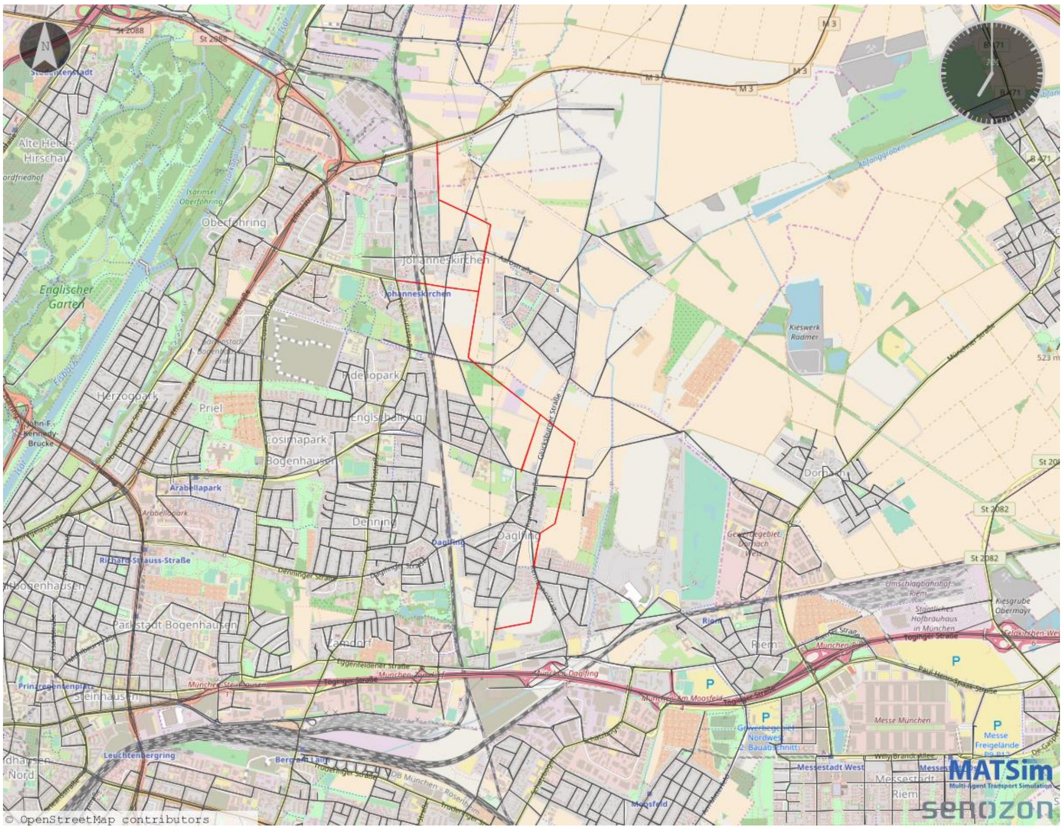


Figure 6  Private Transport Network – Scenario 1

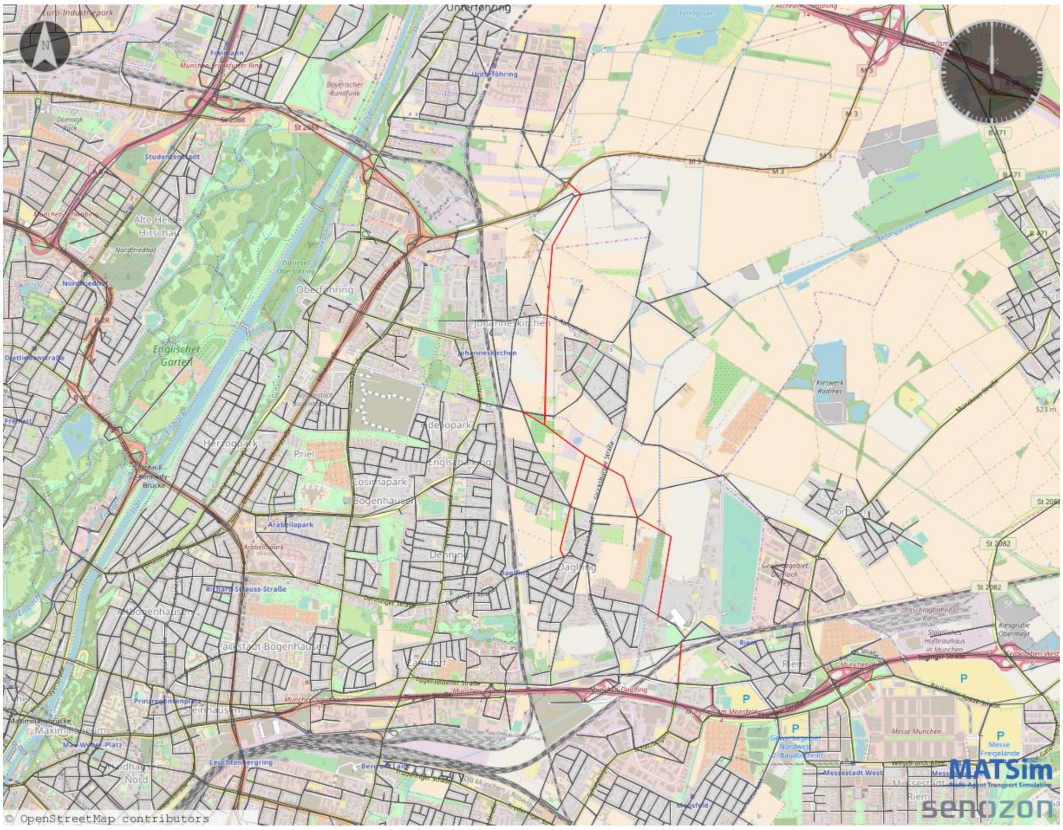


Figure 7  Private Transport Network – Scenario 2

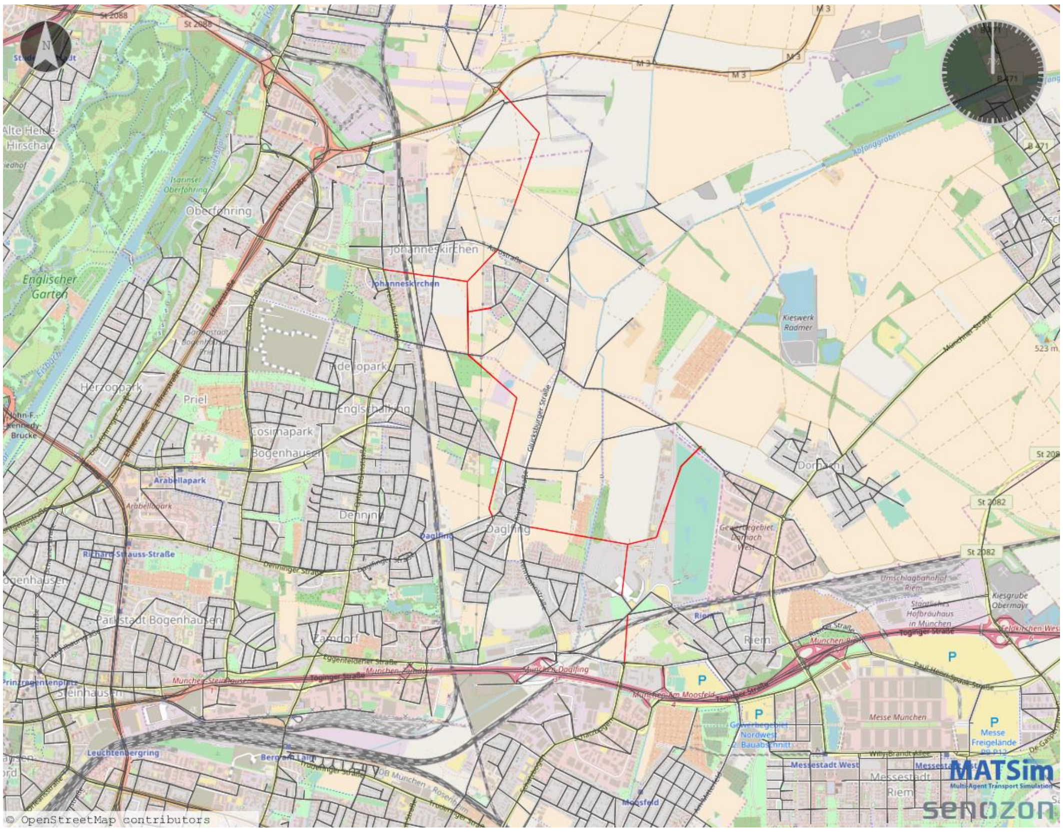


Figure 8  Private Transport Network – Scenario 3

# E. Public Transport Travel Times

An approximate travel time for new links with the extended U4 line is shown in

Table 13 Public Transport Travel Times for the Proposed U4 Line Extension

| Link | Station From | Station To | Travel Time (seconds) |
|---|---|---|---|
| **Scenario 1** | | | |
| 1 | Arabellapark | New (1) | 60 |
| 2 | New (1) | Englschalking | 60 |
| 3 | Englschalking | New (2) | 60 |
| **Scenario 2** | | | |
| 1 | Arabellapark | New (1) | 60 |
| 2 | New (1) | Englschalking | 60 |
| 3 | Englschalking | New (2) | 80 |
| 4 | New (2) | Riem | 80 |
| 5 | Riem | Messestadt West | 60 |
| **Scenario 3** | | | |
| 1 | Arabellapark | New (1) | 60 |
| 2 | New (1) | Englschalking | 60 |
| 3 | Englschalking | New (2) | 60 |
| 4 | New (2) | New (3) | 100 |
| 5 | New (3) | Riem | 60 |
| 6 | Riem | Messestadt West | 60 |