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Earth Observation and Open Geodata for Sustainable Urban Planning – A Practical Case Study from the City of Munich, Germany

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1 ABSTRACT

Cities are hot spots of development and urbanization is a persistently ongoing phenomenon worldwide. Also in Germany, where the urbanization rate is already at the high level of 80%, the ongoing shift towards cities puts increasing pressure on land use and urban planning. The challenge of competing land uses is particularly evident in densely built-up urban areas and their immediate surroundings, where housing, industry, transportation, and open spaces compete for limited space already in the planning phase.

In this study, we investigate a major urban development project by the city of Munich which aims to create a completely new urban district for up to 30,000 new residents. At present, the project has been approved by the city council, and an initial draft plan is already available. This plan is undergoing further review in various areas (e.g., transport, climate, ecology) in order to refine the draft. The practical implementation of the project is scheduled for the 2030s.

To support the ongoing debates on the practical design of the new district, we utilize Earth Observation data with very-high spatial resolution in combination with open geodata to investigate the current status of land use and land cover (LULC) within the study area, as well as the entire city of Munich. On this basis, we focus on the analysis of new urban development areas that were finalized during the past decade in Munich, which serve as practical examples of potential construction in the new district. The effect on LULC is not only illustrated visually but also evaluated quantitatively based on geospatial data. In addition to the analysis of changes in LULC, we also provide a statistical estimate of the resulting living space for the new residents based on Earth Observation and other geodata. Finally, the study examines possible implementations not only of built-up areas, but also developments and potential changes in open spaces.

With this set of data, methods, and geoinformation, this study makes a contribution to the discussion on the design and implementation of new urban development projects. It is applicable to projects at all scales and provides an illustrative view of the impact of planning projects in the targeted area. In addition, it allows to support decision making and also adds to the public debate on competing land uses on limited space, which is particularly crucial in urban areas.

Keywords: Earth Observation, urban planning, land consumption, population estimation, Munich, Germany

2 INTRODUCTION

Urbanization is an ongoing phenomenon worldwide which leads to a persistent demand for housing in cities (Taubenböck et al. 2024). This is accompanied by expansion of cities and continuous development of new districts. However, in many cases around the globe, the construction of new residential districts and the provision of housing do not match the actual demand, resulting in housing shortage and rising prices (van Doorn et al. 2019).

In Germany, with an urbanization rate at the high level of 80% according to official statistics (UN, 2020), urbanization remains steady with a continuous demand for housing (Shahab et al. 2021), especially in economically strong metropolitan areas like Munich (Müther and Waltersbacher 2025). In this context, targeted and future-oriented land use and urban planning plays an indispensable role not only to meet the demand for housing, but also to preserve the quality of life in cities and enable them for future challenges, e.g. associated with climate change (Gupta et al. 2025).

Earth Observation (EO) has proven a suitable tool for monitoring of land use and land cover (LULC) and to support land use and urban planning (Bielecka et al. 2025). In particular, EO-based data and derived information with very-high spatial resolution (VHR) offer a suitable basis for application in urban environments, where diverse objects and land cover are concentrated in a highly dynamic manner at small spatial scale, and thus, sufficient spatial resolution to capture all details is essential. This allows not only the detailed assessment of LULC and its changes to date within the area under study, but also scenario simulations and relative comparisons across locations for quantification of the impact of planning decisions (Wang et al. 2021). In addition, EO in combination with open geodata facilitates population estimation beyond official census data or planning estimates, providing consistent and area-wide information (Leichtle et al. 2019, Stevens et al. 2015). Finally, EO- and Geographic Information System (GIS)-based methods support the illustration and elaboration of the effect of LULC changes as a result of planning decisions and urbanization on a specific area (Wellmann et al. 2020).

In this study, we demonstrate the potential of VHR EO and open geodata for application in the context of a major urban development project in Munich, Germany. This work aims at the illustration and quantification of potential LULC changes as a result of planning, while also considering different scenarios in an early stage of planning. In particular, we focus on the assessment of residential housing capacity, which is crucial with regard to overcoming the shortage of housing today and in the future.

3 STUDY AREA & DATA

The study area is located in the city of Munich, which covers an administrative area of 310 km² and represents one of the most dynamic metropolitan areas in Germany. At the end of the year 2024, Munich housed around 1.60 million inhabitants, while this number is estimated to increase to 1.83 million in 2045 (Landeshauptstadt München, 2025a). The projected population growth of 14.1 % over the next two decades underlines the urgent need for adequate urban planning in order to meet the housing demand and to ensure sustainable urban development.

3.1 A New Urban District in Northeast Munich

As part of the general urban development plan of the city of Munich, an area of 600 ha in northeast Munich represents one of the major urban development projects of the coming decades (https://stadt.muenchen.de/infos/zukunftsquartier-muenchner-nordosten.html). In this area, it is planned to establish a new urban district for up to 30,000 new residents. At present, the project has been approved by the city council and an initial draft plan is available as a result of an idea competition. It delineates areas of different land use, including built-up areas, green spaces, natural green areas, and activity areas, as well as an initial plan for public and private transport (Figure 1). The initial plan is currently undergoing further review in various sub-areas (e.g., transport, climate, ecology) in order to refine the draft. The practical implementation of the project is scheduled for the decade after 2030.

3.2 Earth Observation and Open Geodata

In this study, we use different sources of geospatial data in order to conduct a comprehensive assessment across multiple dimesnions.

VHR EO data is collected by the WorldView mission with a pixel size up to 30 cm. For Munich, a cloud free WorldView-3 scene covering eight spectral bands is used, which was acquired on 04.07.2019 and provided by European Space Imaging (EUSI, www.euspaceimaging.com). Height information is included through a normalized Digital Surface Model (nDSM) with a spatial resolution of 50cm provided by the city of Munich. In addition, data from Open Street Map (OSM) covering the same time period is employed. Building envelopes are obtained as Open Data from the Free State of Bavaria.[1] For visualization and illustration purposes, aerial imagery from the Open Data Portal of Bavaria are used.

[1] https://geodaten.bayern.de/opengeodata/

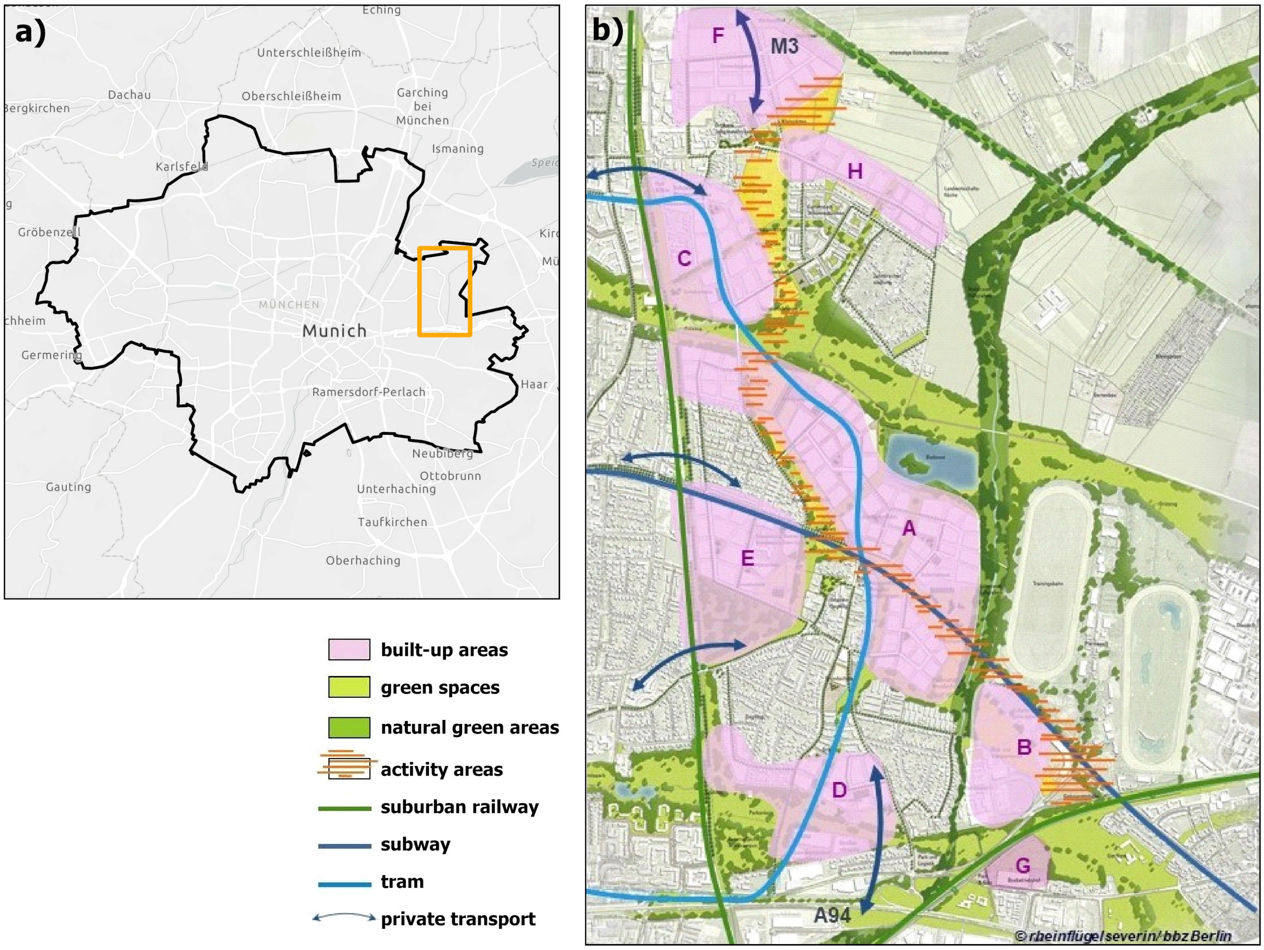

Fig. 1: Location of the study area within the city of Munich (a) and initial draft plan of the new district in northeast Munich (b).

4 METHODOLOGY

The methodology of this work consists of four main steps which are described in the following.

First, in order to derive a spatially consistent data basis on the current situation of LULC, an object-based classification approach based on the methodological foundations introduced in Taubenböck et al. (2010) and Wurm et al. (2011) is implemented. This approach relies on the WorldView-3 imagery, the VHR nDSM, OSM data, and the building envelopes. Target classes include “buildings”, “impervious surfaces”, “bare soil”, “trees”, “low vegetation”, and “water”. The quantitative evaluation of classifiaction accuracy is realized through visual collection of reference samples at randomly distributed locations.

Second, practical examples of existing residential built-up areas and open spaces across Munich are used for evaluating potential realizations of residential construction or types of open spaces in the new district. These are collected across the entire city of Munich, covering open spaces as well as built-up areas. Reference areas for open spaces (i.e. green spaces, natural green areas, and activity areas) are collected regardless of their construction date throughout the city. For built-up areas, we select three new urban developments in Munich that were finalized during the past decade, in order to take current architectural concepts and trends into account.

Third, for the assessment of the potential effects of the new development in northeast Munich, the current land cover of open spaces and built-up areas according to the draft plan is determined based on the EO-based land cover classification. This is compared to the statistical distributions of the land cover classes from the reference areas, i.e. open spaces as well as the three examples of residential built-up areas.

Finally, we conduct a statistical estimation of avaiable living space for the three existing types of residential construction that serve as practical examples of new urban development in Munich. For each individual building, the number of floors is multiplied with the building area to derive floor area per building (Leichtle et al. 2019). The number of floors in each of the three reference areas is assessed by manual inspection and extrapolated according to built-up areas in the draft plan of the new district in northeast Munich. To account for uninhabited areas within buildings, such as balconies or stairwells, a uniform 10% of the living space per building is deducted (Landeshauptstadt München, 2025b). Based on the available living space, the potential population is calculated using an average living space of 39.5 m² per person (Landeshauptstadt München, 2025b).

5 RESULTS

5.1 Land Cover Classification

Figure 2 shows the result of the object-based classification of land cover using VHR remote sensing. Besides the WorldView-3 imagery acquired on 04.07.2019, the VHR nDSM, OSM data, and building envelopes are considered in this approach. Accuracy assessment based on visual inspection of randomly distributed points within the study area resulted in 88% overall accuracy. For further analysis in this work, the original land cover classes are aggregated as shown in Figure 2.

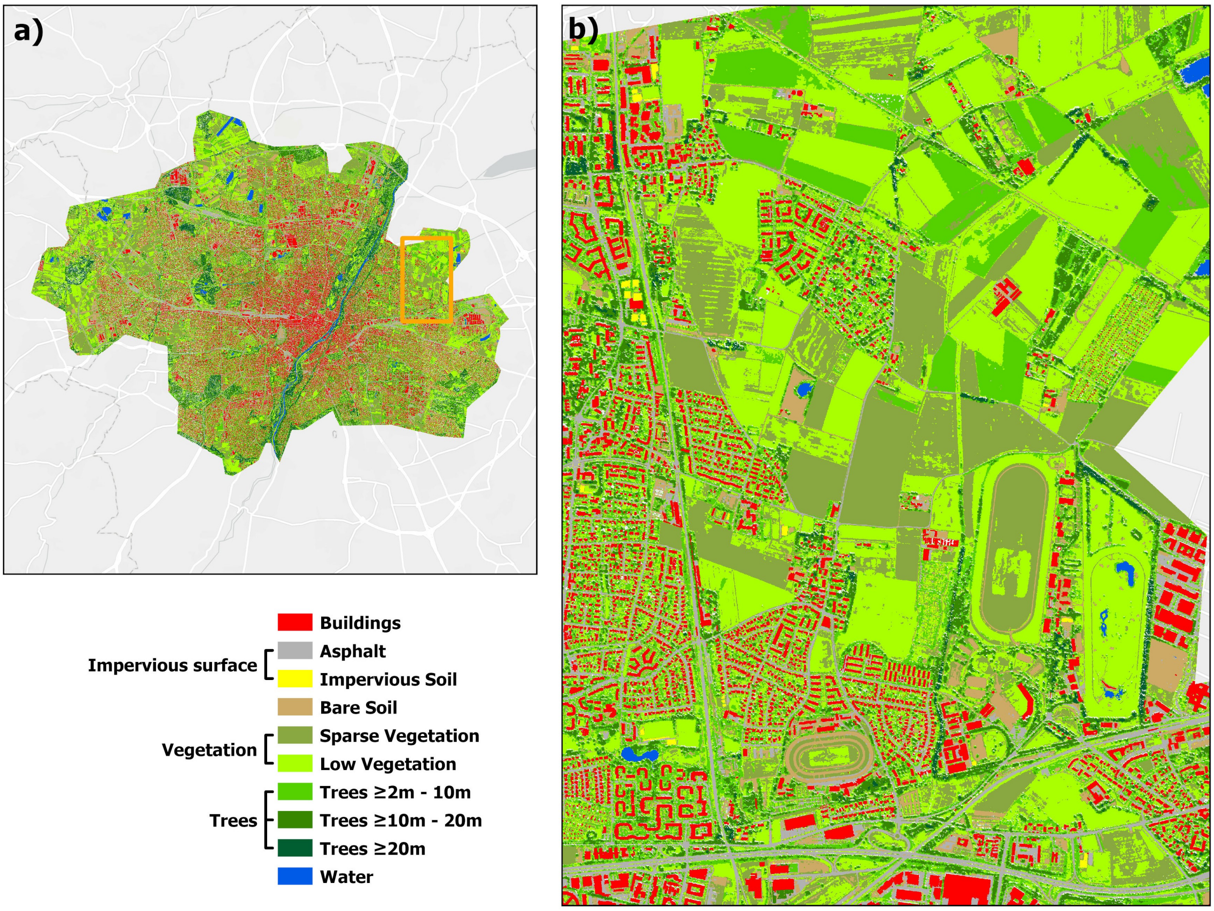

Fig. 2: Land Cover classification based on the WorldView-3 imagery acquired on 04.07.2019, the VHR nDSM, OSM data, and building envelopes. Overview of the city of Munich (a) and detailed view of the new district in northeast Munich (b).

5.2 Collection of Reference Areas

Since the design and implementation of open spaces as well as the type of development on built-up areas in the new district are not yet determined in the early planning phase, reference areas across the entire city of Munich serve as examples of potential realizations. The locations of reference areas for built-up areas, green spaces, natural green areas, and activity areas are illustrated in Figure 3. For built-up areas, three new urban developments that were finalized during the past decade were selected.

Fig. 3: Location of reference areas for residential built-up areas (new urban developments from the past decade), green spaces, natural green areas, and activity areas within the city of Munich.

Aerial views, spatial statistics of land cover, and illustrations of the three selected new urban developments are summarized in Figure 4.

The first example, “Siemenswerke Obersendling” (Figure 4, left), is a new development in the south of Munich with five high-rise buildings with 15 floors each, which are surrounded by peripheral development with four to five floors. This development was completed in 2014 and features a car-free design with access and parking spaces via the surrounding streets. The land cover of this example has the highest share of vegetation of 51%, with the fewest trees, while building density as well as impervious surfaces are the lowest among the three examples.

The second example, “Neue Gärten Giesing” (Figure 4, middle), is located southeast of the city center and represents a relatively central location within Munich, which was completed in 2014. This development is implemented in a car-free design and features dense residential development with four to seven floors. The land cover of this development features the highest tree density of 8% with medium vegetation cover. Building density of 27% and impervious surfaces of 15% are in the medium range compared to the other examples.

The third example, “Mein Aubing” (Figure 4, right) in the west of Munich, is designed in a conventional layout (i.e. access through motorized individual transport) with buildings of two to three floors. The location of this development can be characterized as a traditional suburban setting; its construction was completed in 2015/16. Due to the presence of roads, this development has the highest share of impervious surfaces of 24% and low values of vegetation and tree cover with 27% and 5%, respectively. Building density of 31% is the highest among the three examples.

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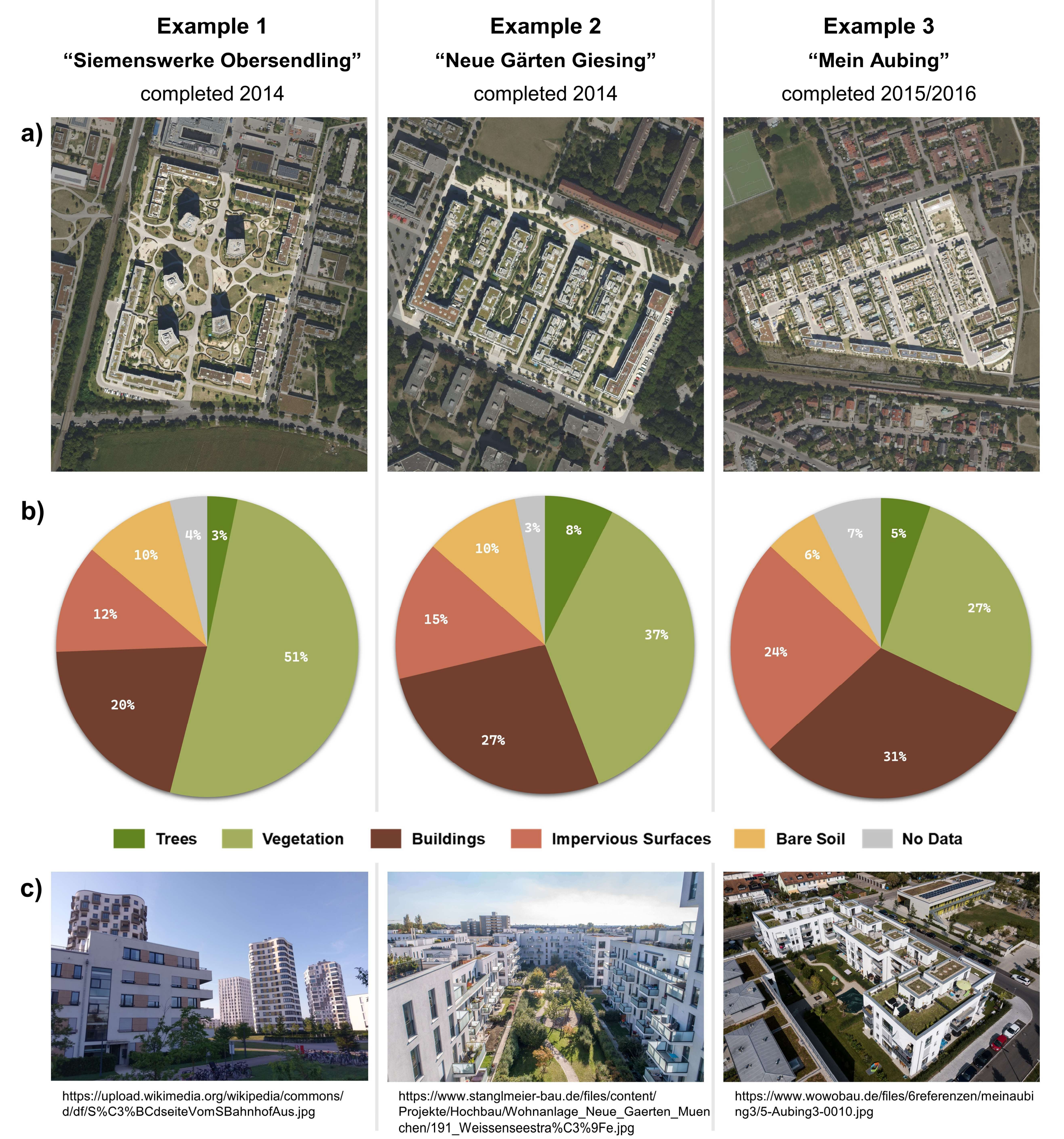
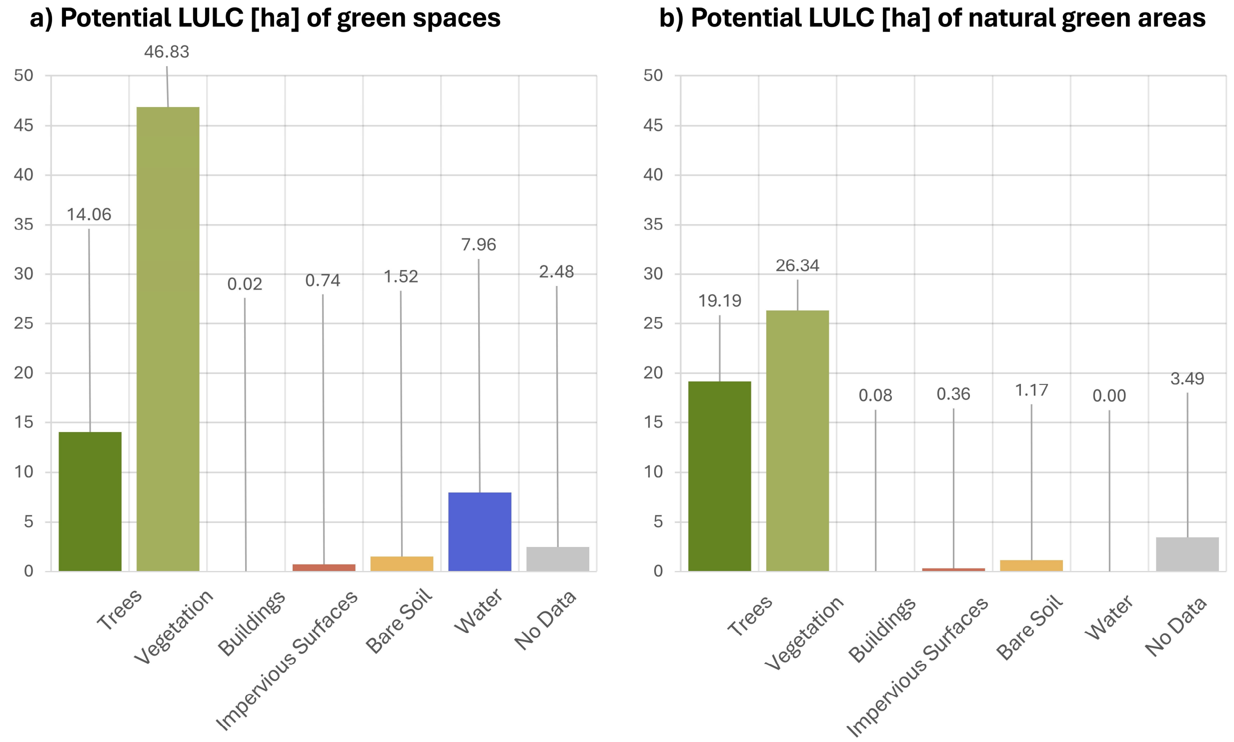


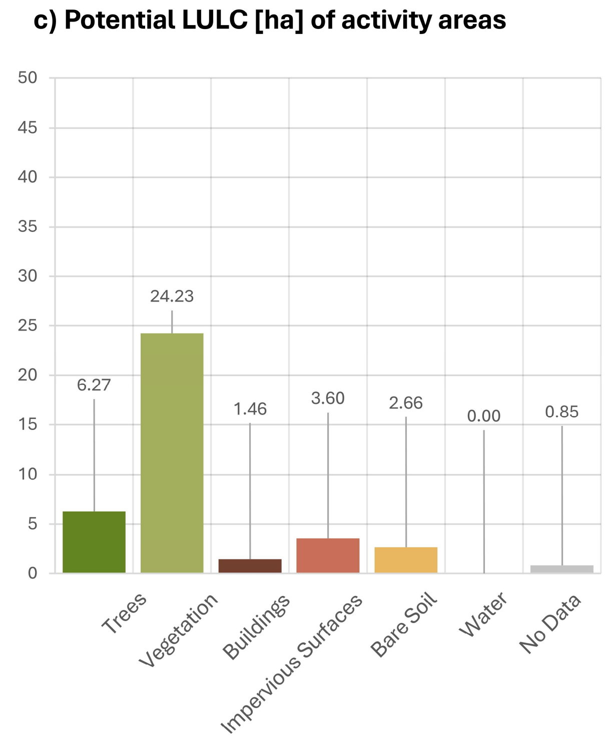
Fig. 4: Aerial views (a), spatial statistics of land cover (b), and illustrations (c) of the three exemplary new urban developments. For locations of these areas refer to Figure 3.

5.3 Effects of new development

For the analysis of potential effects of the new development, we use the collected reference areas of open spaces as well as the three selected examples of residential construction to evaluate the impact on the new district.

For the estimation of the effects of planning in open spaces, we assume that tall (>20m) and medium-tall (≥10m-20m) trees are retained, while other areas are altered according to the distibution of land cover in the reference areas. The resulting potential realizations for green spaces, natural green areas, and activity areas are depicted in Figure 5. Overall, vegetation and trees account for the majority of LULC in all three types of open areas. In green spaces (Figure 5a&d), vegetation and trees represent 63.6 and 19.1% of land cover, respectively. In addition, water makes up 10.8% of the total area, which is included through the recreational lake in the center of the planning area (Figure 1b). For natural green areas (Figure 5b&d), vegetation and trees are more evenly distributed with 52.0 and 37.9%, respectively. As excepted, these areas can be characterized as the most natural, with lowest shares of impervious surfaces and buildings, and highest shares of green space. Finally, activity areas (Figure 5c&d) possess similar distributions of vegetation and trees as green spaces with 62.0 and 16.0%, repsectively. The most pronounced difference are notable shares of buildings (3.8%) and impervious surfaces (9.2%), as well as bare soil (6.8%). Obviously, this is explained by new construction of infrastructure for pedestrian and bicycle traffic as well as areas for sports and leisure activities, which, depending on their use, include both buildings and impervious surfaces. In addition, activity areas also comprise areas for playgrounds, seating, relaxation, and recreation.





d) Shares [%] of potential LULC in each area

	a) Green spaces	b) Natural green areas	c) Activity areas
Trees	**19.1**	**37.9**	**16.0**
Vegetation	**63.6**	**52.0**	**62.0**
Buildings	**0.0**	**0.2**	**3.8**
Impervious	**1.0**	**0.7**	**9.2**
Bare soil	**2.1**	**2.3**	**6.8**
Water	**10.8**	**0.0**	**0.0**
Nodata	**3.4**	**6.9**	**2.2**

Fig. 5: Potential change per land cover class for green spaces, natural green areas, and activity areas in the new district in northeast Munich.

For built-up areas, the potential effect of the three exemplary new urban developments is illustrated in Figure 6. On the one hand, new development is accompanied by a loss of natural and near-natural areas, as evidenced by the loss of trees, vegetation, and water bodies in all three examplary new urban developments. On the other hand, new development results in an increase in buildings and impervious surfaces, with the magnitude differing significantly for the three different construction types. The lowest land consumption through built-up areas can be observed for the first example (Siemenswerke), which is very space-efficient based on the high-rise buildings. This is accompanied by a high amount of open space in between the buildings, which is covered by vegetation in this example, resulting in the relatively lowest loss of vegetation. The second example (Giesing) is characterized by a moderate land consumption by buildings and impervious surfaces, whereas the loss of trees is lowest in this example. Finally, the third example (Aubing) of new urban development exhibits the highest building density as well as the highest degree of imperviousness, which can be attributed to the inclusion of motorized private transport and the corresponding space requirements of associated infrastructure.

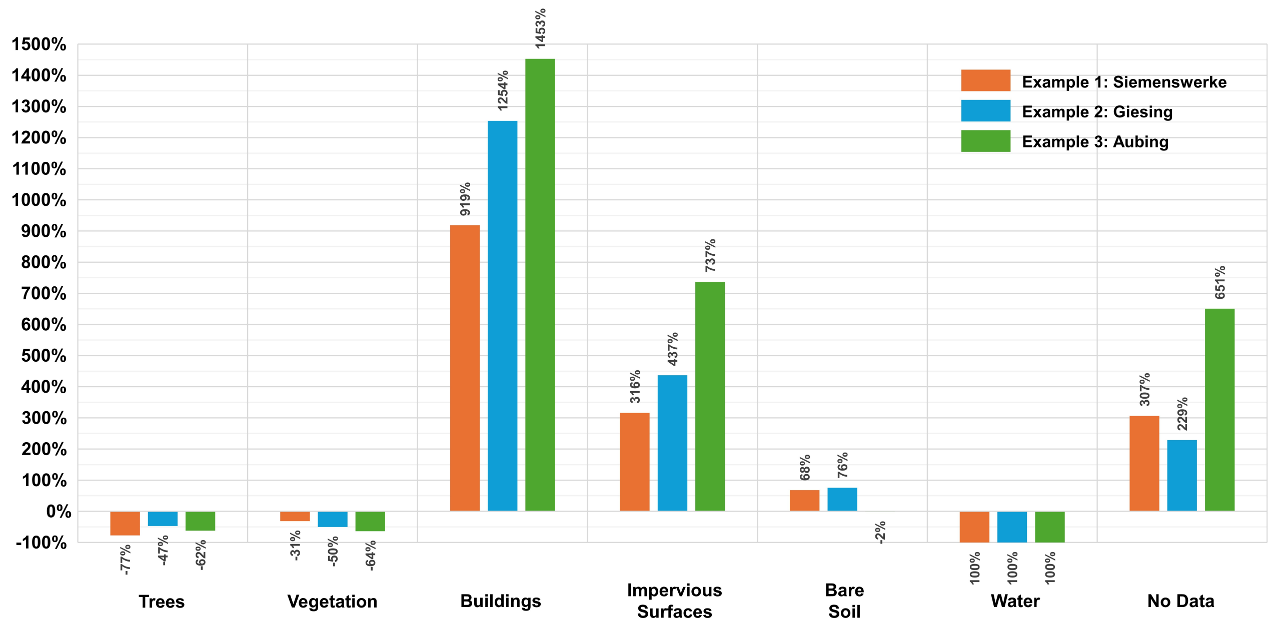


Fig. 6: Potential change per land cover class for built-up areas based on the three exemplary new urban developments in the new district in northeast Munich.

5.4 Estimation of Living Space

The statistical estimation of the potential population capacity based on an average living space of 39.5 m² per person is presented in Figure 7.

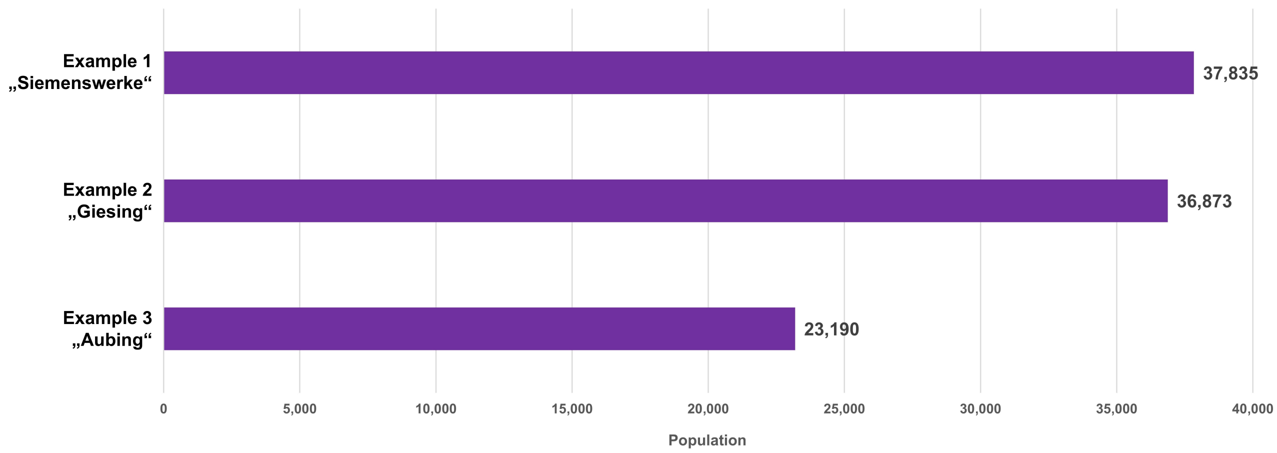


Fig. 7: Potential population capacity for the three exemplary new urban developments in the new district in northeast Munich.

Based on the avaiable areas for built-up development in the new district in northeast Munich, the estimation for the third example "Aubing" is significantly lower, while the other two examples are significantly above the envisaged population capacity of 30,000 inhabitants from the draft plan. While the estimated population capacities of the first and second examples are close, the two types of construction show clear differences in terms of building density and height, and consequently different possibilities for open space design between the buildings (also see Figure 4). Overall, these results illustrate the potential variation of up to 15,000 inhabitants dependent of different conceptualizations of new urban development, i.e. by implementation of a car-free design and/or construction of high-rise buildings.

6 DISCUSSION

This work demonstrates the capabilities of EO and open geodata for illustration and quantification of potential effects of LULC change as a result of urban planning. According to the draft plan of a major development project in northeast Munich, we demonstrate potential LULC changes differentiated by open spaces and built-up areas, whereas for the latter, three specific of recent residential developments in Munich and their different impacts are examined. In addition, not only the impact on land consumption but also the provision of housing in terms of residential living space is examined.

Compared to existing research on urban land management and planning, the utilized VHR EO data and open geodata was rarely used to date (Bielecka et al. 2025). While VHR satellite imagery – like the WorldView data employed in this study – is usually not freely available and requires some processing effort (Wurm et al. 2011), the derived information is highly valuable to support urban planning. However, despite very-high resolution information, not all aspects can be resolved, e.g. small water bodies or impervious surfaces that are topped by tree crowns and thus, become invisible from a satellite view. In addition, VHR remote sensing classification results usually have a remaining error in the order of 10%, which also entails a certain degree of uncertainty. However, in general, the VHR data basis offers good transferability and applicability to different areas and thus, is a valuable source of information for applications in urban planning.

Overall, the estimated LULC changes in this work are highly dependent on the choice and selection of reference areas that are used to project the effects of planning in the target area. With regard to open spaces, we aimed to collect a high number of different areas across the entire city of Munich in order to reach a sufficient degree of representativeness. Activity areas can take a variety of different forms, combining infrastructure for pedestrian and bicycle traffic with areas for sports and leisure activities, including various proportions and combinations of buildings, impervious surfaces, and bare soil. However, due to their wide range of possible configurations, the specific characteristics of activity areas are difficult to foresee for specific study cases, and individual implementations may vary considerably. With regard to built-up areas, the derived LULC changes are consistent with our expectations, i.e. loss of vegetation and tree cover accompanied by an increase of impervious surfaces and buildings. The three examples of new urban developments in Munich were chosen to serve a range of residential development characteristics; however, their practical feasibility was not assessed within the scope of this work. However, our approach highlights the bandwidth of building density and impervious surface, as well as consequently different shares of vegetation and trees in the neighborhoods that will be constructed. In addition, the estimation of potential living space and population capacity facilitates the illustration of the impact of planning decisions by presenting them in tangible figures not only for experts but also for the general public. This quantification not only shows the potential of variation, but also offers practical perspectives for discussions about possibilities for urban development and design during the planning phase.

In general, planning decisions are often highly influenced by practical and political factors that were not considered in this work. Especially the political aspect of planning decisions is hard to take into account, which is also closely tied to the role of public sentiment and citizen participation (Mitlin 2021). However, it was proven that geospatial data and GIS methods improve public participation in the planning process (Kahila-Tani et al. 2019). From a practical perspective, the feasibility and cost of different realizations for new developments can vary considerably (Hu & Skibniewski 2021), which was not considered in this study. Sustainable urban planning was included from the perspective of housing provision, which plays an important role, particularly in dynamic urban environments such as the city of Munich. However, future research should include other aspects of sustainable urban planning, such as renewable energy, sustainable building materials, and the provision of green spaces. Particularly in view of advancing climate change, aspects of the urban climate and urban green infrastructure will be crucial for urban planning in order to ensure sustainable development and maintain the quality of life in cities.

7 CONCLUSION

This study illustrates and quantifies the potential impacts of a new urban development in northeast Munich. Based on EO and open geodata, we highlight land consumption in different areas of the currently available draft plan of the planning area. This work particularly focuses on built-up areas, where not only the impact of three different exemplary realizations of residential development is demonstrated, but also their population capacity is estimated in order to address the aspect of housing provision.

This work supports the discussion on adequate provision of living space and the demand for housing in urbanized areas of Germany and beyond. Furthermore, our selection of geospatial data, methods and derived information is well-suited to illustrate and elaborate the effect of planning decisions beyond subjective perception, in order to objectify the debate and explain the context and implications also to non-experts.

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