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Addressing Inequalities in the Distribution of Transport Benefits. Based on an Analysis of the Accessibility of selected Areas in Vienna.

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Ass. Prof. Dipl. Ing. Dr. techn.

Bardo Hörl

Forschungsbereich Verkehrssystemplanung

Fakultät für Architektur und Raumplanung

Technische Universität Wien

Associate Professor Dr.

Bing Liu

Urban Planning Department

College of Architecture and Urban Planning

Tongji University Shanghai

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von

Marta Gerstner, BSc

01427204

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Abstract

The social implications of urban transport systems have been discussed in the context of transport justice, which thematizes the distribution of transport benefits and burdens. Accessibility, the ease of reaching destinations, is acknowledged to be the main transport benefit. A lack of accessibility is likely to reduce people's opportunities and to enhance social exclusion. For the case of Vienna, social implications of the transport system have so far not been discussed as a matter of justice. Thus, this thesis aims at identifying possible inequalities in the distribution of accessibility levels and at exploring how differences originate, in order to derive recommendations for the local and city level.

Accessibility levels for four case study areas are measured using a location-based approach, in which destinations – jobs, centers and central areas in this case - are ranked according to their attractivity, and travel time represents the impedance to reach the destinations. Travel time calculations rely on GIS-models. Results are compared between areas and modes.

The accessibility indicators for each area and transport mode indicate important differences between the analyzed areas in Vienna, especially in public transport. These gaps reveal an unequal distribution of transport benefits, that ought to be addressed to avoid mobility-related exclusion of certain groups. Specific measures for improvement need to be tailored according to the local built and socioeconomic environment. Furthermore, distributional goals should be adopted in transport and land use planning and the according indicators are to be established as mean to make the social implications of planned measures tangible and assessable.

Key Words: *Transport Justice, Accessibility, Urban Mobility, Vienna*

Kurzfassung

Die sozialen Effekte von städtischen Verkehrssystemen sind Thema im Forschungsfeld der Verkehrsgerechtigkeit. Erreichbarkeit, ein Maß für die Zugänglichkeit von Orten und Aktivitäten, wird dabei als wichtigste positive Externalität anerkannt. Ein geringes Erreichbarkeitsniveau wird mit schlechteren Chancen im sozialen und beruflichen Kontext in Verbindung gebracht und kann zur Verstärkung von Exklusionsprozessen beitragen. Verteilungsfragen im Kontext von urbaner Mobilität sind im Falle Wiens bislang kaum thematisiert worden. Diese Arbeit zum Ziel, mögliche Ungleichheiten in der Verteilung von Erreichbarkeitsniveaus zu identifizieren und Faktoren zu erkunden, die maßgeblich Einfluss auf die lokale Erreichbarkeit ausüben. Darauf basierend werden Empfehlungen für die lokale und Stadtebene abgeleitet.

Indikatoren für die Erreichbarkeitsqualität von Arbeitsplätzen, Zentren und zentralen Gebieten werden für vier Fallbeispiele in Wien mit einem ortsbasierten Ansatz berechnet. Dabei werden die Ziele nach ihrer Attraktivität gewichtet und die Reisezeit zwischen Analysegebiet und Ziel als Impedanz herangezogen. Schließlich werden die berechneten Indikatoren für die Erreichbarkeitsqualität zwischen Gebieten und Verkehrsmodi verglichen.

Die Ergebnisse zeigen relevante Unterschiede in der Erreichbarkeitsqualität der analysierten Fallbeispiele auf, vor allem im öffentlichen Verkehr. Diese Unterschiede machen deutlich, dass Verteilungsfragen in Bezug auf positive Externalitäten des Verkehrs auch in Wien von Bedeutung sind und dass sie deswegen aktiv adressiert werden müssen. Die Analyse der Fallbeispiele hat zudem gezeigt, dass konkrete Maßnahmen an die lokalen Gegebenheiten angepasst werden müssen. Distributive Zielsetzungen sollen in der Verkehrs- und Stadtplanung aufgenommen werden und entsprechende Indikatoren, wie etwa Indikatoren für die Erreichbarkeitsqualität, sollen herangezogen werden, um die sozialen Implikationen von geplanten Maßnahmen mess- und interpretierbar zu machen.

Schlüsselbegriffe: *Verkehrsgerechtigkeit, Erreichbarkeit, städtische Mobilität, Wien*

摘要

城市交通系统的社会影响已经在交通正义的背景下进行过广泛讨论，交通正义通常以交通利益和负担的分配为主题。可达性，即到达目的地的便利性，被认为是主要的交通优势。缺乏可达性会减少人们的机会，并可能加剧社会排斥。就维也纳而言，交通系统的社会影响迄今尚未就正义问题进行过讨论。因此，本文旨在确定可达性水平分布中可能存在的不平等，并探索在特定情况下影响可达性水平的因素，以便为地方和城市层面提供建议。

本文中，四个案例研究区域的可达性水平是基于位置的方法进行衡量的，其中目的地，即工作、中心和中心区域，根据其吸引力进行排名，而出行时间代表到达目的地的阻力。出行时间计算依赖于 GIS 模型。 最终，计算出的可达性水平在不同的区域和模式之间进行比较。

文章结果表明维也纳的分析区域之间存在重要差异，尤其是在公共交通方面。 这些差距揭示了交通福利分配的不平等，应该加以解决这一问题，以防止与流动相关的某些群体受到排斥。该案例分析证明，具体措施需要根据当地的建成环境和社会经济环境量身定制。此外，在交通和土地使用规划方面应采用分配目标，并建立相应的指标，作为使计划措施的社会影响切实可见和可评估的手段。

关键词: *交通正义， 可达性， 城市流动， 维也纳*

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1. Introduction

1.1. Introduction to the topic

Although ecological aspects have dominated public discussions on urban mobility in the last years, **increasing attention** has also been laid upon the **social effects of urban mobility networks and services**. The benefits and burdens, such as air and noise pollution, accidental risks, but also higher accessibility and freedom of mode choice, that inevitably emerge from any allocation of funding in the transport system have moved into the focus of discussions. Moreover, administrative, and political entities at different levels have by now started to acknowledge the importance of the social aspect for long-term sustainability and prevention of social segregation processes. Thus, understanding or at least getting insights into the social effects of current urban transport systems is essential for facilitating future good practice in urban and transport planning.

Looking at the development of the **social meaning of transport**, it has changed considerably during newer history. The spread of private car ownership among big parts of the population, as well as the development of high-capacity public transport have allowed functions within the city to spread widely (Martens et al. 2012: 684ff). Following the rationale of Martens et al. (ibid: 868f) there are currently two predominant set of values when discussing the social dimension of transport. The first one comprises values of freedom and autonomy and is related to the concept of **potential mobility**. This is defined as the ease with which a person can move through space (Sager, 2005: 4). The second set of values represents the **functional dimension of transport**, which is its **role in enabling people to engage in desired activities**. This fits with the definition of **accessibility**, defined as the ease with which a person can reach destinations from a given location in space (Farrington & Farrington, 2005).

Having a **distinctive social meaning** (Martens et al., 2012: 868f), **transport benefits and burdens**, as well as their distribution amongst population must be reflected on. Whereas distributional inequalities of certain negative externalities of the current transportation system, such as environmental pollution or noise, have widely been acknowledged (Gössling 2016: 1), social benefits and burdens resulting from transportation systems are less present in discussions. However, decisions on urban transportation systems taken both by the public and the private sector, have a series of positive and negative effects on people travelling within and being dependent on the system. As transport in its functional dimension fulfils a key role in satisfying the population’s transport needs, the availability of transport modes and accessibility of destinations significantly shapes people’s life opportunities (Lucas, 2006: 809). **Urban transportation**, together with land use planning, subsequently **must also be regarded as a matter of social justice**.

Accessibility can be said to be **the most important transport benefit**, as people's life is shaped significantly by the need of accessing goods, services and social networks that facilitate participation in society. Several authors relate lack of access to opportunities to a greater risk of social exclusion (Foth et al. 2013; Kenyon et al., 2011; Lucas et al. 2018). Thus, the concept of access is closely related to distributional questions and the goal of equal opportunities (Gössling, 2016: 5).

Based on the impact that accessibility to important destinations can have on people's life and participation in societal processes, **accessibility measures have been introduced as evaluation metric for transportation in various countries** (ibid: 39f). The intention is to that way be able to address equity questions in transportation and land use planning. For example, the government of the United Kingdom put in place a framework for accessibility planning at the local level of policy delivery. Within this framework, the key aim is to ensure that local **decision-makers have improved information on the areas where accessibility is the poorest** and on the barriers to accessibility from the perspective of the people who are living there (Lucas, 2006: 804).

Various **scholars advocate for a shift from mobility orientated planning**, which aims at providing more or faster mobility, **to an accessibility orientated planning,** which should be based on the question which destinations can be reached and how easily this can be done for different groups of individuals (Nazari Adli & Donovan 2018; Foth et al. 2013; Gössling, 2016; Lucas et al. 2018; Martens et al. 2012; Neutens et al. 2010). According to Lucas (2006: 808), accessibility planning can lead to a fundamental review of transport spending, as measuring accessibility allows to demonstrate how transport impacts are distributed across geographical areas, population groups, trip purposes and modes of travel.

This thesis aims at **approaching transport planning in Vienna from a justice-orientated perspective**. It is based on the rationale that public investments in transport infrastructures, together with decisions on land-use patterns inevitably lead to an unequal distribution of potential benefits and burdens (Foth et al., 2013: 1) amongst population and throughout a city It is set in the research field of **transport justice**, which discusses on the distribution on both transport related benefits and burdens. Focus of this work will be laid on getting an insight into the distribution of transport benefits between different areas of Vienna.

For the **case of Vienna distributional questions in the context of transport planning have hardly been discussed**, neither in scientific literature nor in planning practice. Whereas the need for human-scale and eco-compatible forms of transports is directly addressed in the Urban Mobility Plan Vienna (MA18, 2015), neither accessibility nor the fair or equal distribution of transport benefits are mentioned as goals or performance indicators. Also, the Viennese urban development plan *STEP 2025* (MA18, 2014) does not adequately address the aspect of equality related to urban transportation, as will be outlined in chapter 3.2 of this work. Therefore, this thesis aims at initiating the question in how far the distribution of transport benefits might be a relevant topic for mobility planning and urban planning in Vienna.

1.2. Research Questions & Research Design

Parting from the assumption that accessibility or respectively a lack of accessibility has a relevant impact on people's life opportunities and consecutively on social equity, the master thesis will approach the topic of transport justice in Vienna by answering the following research questions:

- ***In how far does the accessibility to jobs and centers and central areas* differ between the analyzed areas and between transport modes?***
- ***Which factors most notably affect the degree of accessibility in the areas?***
- ***Which recommendations can be derived for transport planning and land use policy, in order to address and prevent possible inequalities in accessibility in Vienna?***

* Centers and central areas according to the technical concept "*Centers of urban life. Polycentric Vienna*", enacted by the Vienna municipal council in December 2019 (Based on the current urban development plan STEP 2025)

A basic understanding for possible distributional inequalities related to transport within the city of Vienna is to be generated through assessing **accessibility to job opportunities and centers and central areas of different ranks** for specific case study areas. Different transport modes will be considered, and the results will be discussed in the respective case study area's context. In addition, factors influencing the accessibility levels of the case study areas will be discussed. Relevant factors may encompass location within the city, built structure, but also specifics of the transport network. Eventually, recommendations will be derived, aiming at addressing the found inequalities in distribution of accessibility and contributing to prevent an increase of inequalities in the future.

A **comparative case study approach** was chosen for the research, as this will allow to assess and understand the different factors having impact on the accessibility of certain areas in depth. Moreover, the research can be specified to be of exploratory character, as the aim is to create a basic understanding for how accessibility is influenced in the case of Vienna. A case study is contextualized, it is a detail investigation including the context of the phenomenon under study (Shareia, 2016: 3840). Different sources of evidence, including qualitative and quantitative data will be integrated to understand the analyzed cases. A relevant reason for choosing the case study approach was feasibility within the scheduled time horizon. The calculation times for assessing accessibility can significantly be reduced by restricting the number of areas to be analyzed.

The underlying **research design** for the thesis comprises the following steps. Firstly, to clearly define key words and general concepts crucial for the further work, an in-depth literature analysis has been conducted. Transport justice and the concept of equity, accessibility, as well as different approaches to measure it, are the main concepts to be discussed in the forehand of the research. Moreover, literature analysis encompassed a screening of relevant strategic documents for transport and urban planning in Vienna. The empirical part of the research will be carried out by combining quantitative and qualitative methods. Firstly, quantitative evaluation, making use of a GIS-model, will allow to assess accessibility to jobs and central areas for all case study areas. Secondly, a qualitative comparative approach will be used to find differences and commons in factors influencing the level of accessibility in the areas.

The **empirical work** comprises (1) choosing the areas for the case studies, (2) identifying levels of accessibility for different transport modes for each case study area and (3) comparing accessibility levels and contextualizing them in order to identify possible distributional inequalities.

(1) Choosing the case study areas

Firstly, the case study areas have been chosen according to their fulfilment of the following **eligibility criteria**: location within the city, population density, prevalent residential use, and a set of socioeconomic indicators. **Four case study areas have been chosen** for this thesis. Moreover, to further points in central location of the city have been added for purpose of comparing the distributional range. Details are outlined in chapter 4.2.1.

(2) Evaluating and comparing accessibility

For evaluating accessibility in the chosen areas, a **gravity-based measure** approach was chosen. The evaluation model for accessibility levels has been set up in a geographical information system (GIS).

The following basic information has been included in the models: **origins**, which in this case are the case study areas, **destinations,** the opportunities to be reached - job opportunities and central areas in the present case, **transport network data** and **information on temporal aspects**, including average travel speed and time by mode, as well as public transport schedules and functioning hours.

Firstly, for the **origins**, five random points have been generated within the four case study area polygons, with the idea of generating different anticipated “starting points” from the case study areas. Moreover, additional points in central locations within the city have been included in the origins layer. Assuming that accessibility to opportunities form those points ought to be amongst the highest possible within the city, it has later allowed to better compare differences in levels of accessibility.

Secondly, the **destinations** to be reached had to be defined. For this study, the destinations taken into consideration are **jobs**, based on the most recent available statistical data from 2011 (Statistik Austria, 2011), and **centers and central areas** according to the technical concept "*Centers of urban life. Polycentric Vienna*", enacted by the Vienna municipal council in December 2019 and based on the Urban Development Plan 2025 (MA18, 2020a). All destinations have been rated in terms of attractivity to later include this in the evaluation of accessibility.

Thirdly, the **travel time between origins and destinations** has been calculated. For motorized individual transport and cycling, the ORS (open route service) plug-in for QGIS has been used. This Service is based on a network elaborated from Open Street map data and allows to create origin-destination-cost matrices. For public transport, an own network had to be modelled, making use of the GTFS (general transit feed specification) data provided by *Wiener Linien* (Viennese public transport operator) and *ÖBB* (Austrian railways operator). The modelling and calculation of origin-destination-cost-matrices has been effectuated with the ArcGIS Pro Network Analyst Tool. The result of this step is a time-distance matrix for each mode and area.

Fourthly, accessibility levels had to be made **comparable** by **including travel costs** to the model. To do so, the previous attractivity assessment for all destinations, will be altered in the way that **greater travel time between origin and destinations will mean less attractivity**, representing the assumption that longer travel time makes it less attractive for people to travel to a certain area or destination. The impedance function used for this step ought to be mode-specific, as for example travel times are to be evaluated differently for cycling and motorized transport (Levinson & Wu, 2020: 16f). Summing up the values of attractiveness of all destinations for every area by mode eventually led to results of accessibility levels, which allow to identify differences and distributional gaps.

(3) Comparing and evaluating differences in accessibility between modes and areas

The last step of the empirical work comprised the thorough **analysis of the outcome of the accessibility levels**. The results have been inspected both considering differences between the areas (**space-related equity**) and between different modes for the same area (**mode-related equity**, e.g., is the level of accessibility by motorized individual transport significantly higher than by public transport?).

The accessibility levels or indicators calculated in the previous step of the research have been the basis for reflection and discussion on which factors could be most relevant for the differences. When conducting the comparison, it has been of primary interest to reflect on the differences found and on which factors could have the most notable influence on the accessibility by different transport modes.

1.3. Objectives, Scope and Limitations of the work

The purpose of this thesis is to gain an insight into **differences in accessibility levels to jobs and central areas** within the city of Vienna and thus to **contribute to the intensification of the transport justice debate** in the context of Vienna. In alignment to the research questions, this master thesis encompasses the following research objectives:

- **Identifying the levels of accessibility in the case study areas of Vienna for each transport mode** (public transport, cycling, and motorized individual transport)
- **Identifying differences in accessibility considering both space-related and mode-related equity and discussing possible factors enforcing those inequalities** through reflection on the results in the areas' context
- Finding and developing adequate **approaches to address and prevent inequalities in accessibility** for the specific case study areas, as well as for the city as a whole

Eventually, the **motivation** behind this work is the thought that approaches to make transport related policies more socially oriented are needed in order to balance unequal distributional effects of any improvement (Lucas et al. 2018). As Vienna's transport system, especially the public transport system, is acknowledged to be well-functioning, little research has been done to survey distributional questions on its behalf. However, it seems unavoidable to explore and identify existing inequalities in accessibility and their causes in order to know whether distributional questions in the field of transport planning are relevant in the Viennese context. Based on the results, the third objective of finding approaches to address and prevent distributional inequalities, will also focus on identifying important fields of actions for this purpose.

An additional benefit of this research is that it will demonstrate how accessibility evaluation can be conducted in a simple manner for different areas. It will thus contribute to the research body advocating for accessibility-lead mobility planning.

SCOPE & LIMITATIONS

The research will give a valuable input to the existing body of literature, as case studies broaching the issue of transport justice and accessibility are few in the central European context. Various authors researching in the field of transport justice demand for a greater focus on the analysis of access levels (e.g., Martens et al. 2012: 693), as it gives additional value to planning considerations. However, as mentioned, accessibility as a matter of equity has not been discussed for Vienna. Thus, the findings of this research will help to explore, whether justice-related questions in the transportation field are of importance in the case of Vienna, a city ranked high in terms of quality of life (World Economic Forum, 2019).

However, due to **limited time and personal resources**, limitations of the work have to be clarified in the forehand of the research. It must be mentioned explicitly that it is **not a goal to state, whether the Viennese transport system is fair or not**. Rather than that, the study aims at exploring and understanding differences and possible inequalities between the analyzed areas and between access levels by different transport modes. Although the concept of accessibility is closely linked to transport justice and justice theoretic approaches are part of the underlying theoretical background of this thesis, evaluating justice for the whole Viennese urban transport system is neither feasible nor meaningful within the available time, data, and personal resources.

Also, in order to set a feasible scope to this research, a **location-based approach** to measure accessibility was chosen. This kind of approach allows to evaluate accessibility levels for areas as physically delimited locations but **does not capture a broad range of important individual restrictive factors to accessibility**, such as activity schedules and time budgets, constrained physical mobility, psychological restrictions or language and information barriers (Neutens et al. 2010: 1617). Moreover, legal aspects, including both laws and regulations at the local level, could be another factor that affects individual's opportunities of experiencing same accessibility levels as others. Albeit not especially addressed in this research, the non-discriminatory design of policies in the transport sector has to be paid special attention to. As expressed by Sager (2005: 3), "*circulation in space is influenced by hardware (infrastructure and vehicles) and software (institutions and human behaviour), as well as culture, values and knowledge."* The accessibility levels calculated with a location-based approach will never be able to fully reflect the perceived accessibility by individuals in the analyzed areas. However, it allows to give insight into the distribution of accessibility across space and modes, independent from who is living the analyzed areas.

A further remark on **limitation** to the thesis needs to be done on behalf of the **accuracy of the GIS-model** used to calculate travel times, which are the basis for calculation of accessibility. Neutens et al. (2010: 1613) point out that "*If researchers and practitioners want to make sure that access to urban services is equitable and that no segments of the population are being disadvantaged, they should know how their assessment of accessibility is affected by and dependent on the measurement methodology used*.". For setting up the GIS-Model, which aspires to represent the transport network in Vienna in the best feasible way, various parameters had to be chosen by the researcher. The detailed build-up of the model has been described in chapter 4.2 and the reasons for choosing specific parameters have been elaborated. Although the work has been effectuated in the most conscientious and best way possible, it is undeniable that the model is unable to fully reflect "real" accessibility, which would include even soft barriers, such as cognitive and mental mapping abilities (Lucas, 2006: 805).

A final aspect to consider is that the concept of accessibility focuses primarily on the side of mobility supply. Thus, it is important to clarify that this thesis has **not included any analysis of the mobility demand** in the specific case study areas. However, the demand for transport services and infrastructure is likely to vary depending on the demographic and socioeconomic structure of areas, and eventually this is often an important argument for the allocation of resources.

2. Theoretical Background

The theoretical basis for this master thesis evolves around the broader research field of **transport justice**, which discusses the distribution of transport related benefits and burdens (e.g., Martens et al. 2012; Lucas 2006), as well as the link between transport and social disadvantage (e.g., Kenyon et al. 2012; Lucas et al. 2018; Foth et al. 2013). According to Fransen et al. (2015) there has been a large and growing academic and policy interest in the social implications of transport planning alongside the traditionally well-studied economic and environmental outcomes. Accessibility, the main concept when evaluating transport benefits and their distribution amongst population, has also been widely discussed in literature (Levinson & Wu, 2020; Boisjoly et al. 2017; El-Geneidy & Levinson, 2006; Geurs et al. 2004). Moreover, papers dealing with the implementation of accessibility goals in strategic planning documents and plans (Boisjoly et al. 2017) and with the assessment of transport investments from a transport justice perspective (Foth et al. 2013) can be found.

Most literature has been published in English-speaking countries. Applied studies of accessibility in the context of transport justice deal with the UK (Lucas et al. 2018), US (Owen & Murphy, 2020), Canadian (Foth et al. 2013), New Zealand (Nazari Adli & Donavan, 2018), Chinese (Hu et al. 2017) and the Netherlands context (Cheng & Bertolini, 2013).

This chapter will provide an overview over the broad and rich body of literature related to the topics of transport justice, accessibility, and different approaches to measure it. It will outline these important concepts as basis for the further research.

2.1. The social perspective on Transport Planning

2.1.1. Link between access to opportunities and social exclusion

The **link between transport and its social implications** has been studied in the fields of transport studies, urban studies, and human geography (Schwanen et al., 2015: 123). Notably urban transport systems have been discussed from the social justice theory perspective, including issues such as gender, ethnicity, age, class, and disability, as well as income, accessibility, and social participation (Gössling, 2016: 2). In the case of this research focus is laid on the relation between lack of access to opportunities and social exclusion, which has been outlined by several authors.

People's life is shaped by the need of mobility to access the goods, services and social networks that facilitate participation in society (Kenyon et al., 2002: 211). **Transport** fulfills the need of mobility. Ideally, it **enables individuals to engage in diverse activities**, such as employment, social and leisure activities, public and health services, or shopping. Numerous authors have related insufficient fulfillment of these mobility needs, in other words a lack of access to desired activities, to social deprivation or exclusion (e.g., Foth et al., 2013; Kenyon et al., 2002; Lucas et al., 2018; Nazari Adli & Donavan, 2018; Pyrialakou et al., 2016). Also, the aspect of psychological well-being is likely to be influenced by the ability to access social interactions, employment, learning and other activities (Pyrialakou et al., 2016: 255; Stanley et al., 2011: 790).

The **concept of social exclusion** is generally understood as a **lack of participation in social, economic, and political life**. Contrary to poverty, which focuses on lack of monetary and material assets, social exclusion centers upon the processes of unequal access to participation in society. While being an important concept to tackle inequalities, authors such as Schwanen et al. (2015: 124f) criticize the normatively charged character of social exclusion. They argue that the differentiation only between the binary state of either exclusion or inclusion conveys a process of homogenization that does not adequately reflect reality. They propose to understand **social exclusion as a relative and dynamic phenomenon that can be experienced in different degrees of intensity**. It can affect people both on the neighborhood level and on the individual level (Kenyon et al., 2002: 211). In addition, the authors also point out the problematic fact that the opposite of social exclusion, which would be social inclusion, is often left undefined, which makes determining groups or individuals as “socially excluded” challenging (Schwanen et al., 2015: 125). In this thesis focus will be laid on relative comparison of accessibility and thus of possible social exclusion.

In relation with transport and access to opportunities, the term of **mobility-related exclusion** can be found in literature. Kenyon et al. (2002: 2010) offer the following definition: “*The process by which people are prevented from participating in the economic, political and social life of the community because of reduced accessibility to opportunities, services and social networks, due in whole or in part to insufficient mobility in a society and environment built around the assumption of high mobility.”*

The authors identify two main reasons for lack of accessibility to opportunities. The first is due to insufficient mobility, which can result from gaps in infrastructure or services. The second, which is often forgotten, is the assumption of high mobility. This does not only demand for a perfect allocation of activities and routes connecting them, but also presumes that individuals are perfectly informed and perfectly mobile (Sager, 2005: 6). Thus, the assumption of high mobility does also involve several soft factors on the individual level, that cannot be covered by transport planning and policies.

Nevertheless, it is important to understand the **multiple ways in which the design and organization of transport system can enhance exclusion**. Firstly, geographical and network reasons are highly relevant. Peripheral residential locations and poor transport connections prevent people from travelling to destinations. Further factors relevant for exclusion are physical barriers, monetary cost of travel, time-based factors, fear-based exclusion (e.g., fear of crime) or discouragement by risk of prejudice and discrimination (Schwanen et al., 2015: 125).

The relation between transport and social exclusion is **especially pressuring in the urban context**, as evidence indicates that European cities are increasingly vulnerable to spatial social differentiation (Bunel & Tover, 2014: 1323). From an urban economy perspective, it is likely that high-income households will tend to out-bid low-income households in areas with good access to multiple opportunities. Considering accessibility to be an important amenity, low-income households can be expected to be concentrated in areas that have less of it and vice-versa (Nazari Adli & Donavan, 2018: 57).

However, **mobility-related exclusion is not necessary linked to poverty**. One can be excluded without being poor (Kenyon et al. 2002: 209), and Foth et al. (2013:9) found in their study conducted in Toronto, that the most socially and economically disadvantaged groups had relatively high accessibility and low transit times in the region-wide comparison. Hu et al. (2017: 32f) also were able to prove that highly educated population was significantly affected by reduced job accessibility between 2000 and 2010 in Beijing, whereas low-education population was not.

Based on the arguments exposed in this chapter, the **link between a lack of access to opportunities** that facilitate participation in society and **social exclusion**, or deprivation has evidenced to be relevant. When assessing mobility-related exclusion, evaluation should go beyond a binary system of in- and exclusion, rather **reflecting relative differences within a city as a matter of justice**. Evidence from various specific case studies indicates, that economic deprivation might – but not necessarily must be – a factor increasing the risk of experiencing mobility-related exclusion. Moreover, the multiple individual restraints that influence accessibility and thus may contribute to exclusion must be kept in mind.

2.1.2. Transport Justice – underlying arguments

The concept of social inclusion and exclusion, together with the emerging need for **redistribution of benefits and burdens**, is closely related to justice. **Transport justice** follows the goal of equal distribution of benefits and burdens resulting from the overall transportation system. It can thus be **denominated as a political ideal**, concerned with distribution equality for risks and burdens, but also chances and accessibility (Gössling, 2016: 2).

The **research field of transport justice** addresses the social questions arising from unequal distribution of transport benefits and burdens. Numerous scholars have discussed urban transportation as an issue of justice, including theoretical approaches to the concept of transport justice (Gössling, 2016; Kenyon et al., 2012; Martens et al., 2012) and discussions on transport justice in the context of concrete case studies (Lucas et al., 2018; Lucas, 2006; Martens et al., 2012; Nazari Adli & Donavan, 2018; Schwanen et al., 2015). The academic discussions' justification approaches for why justice should be demanded in the field of urban transportation, involve approaches to define what transport justice could ideally mean, both in theory and in practice, and lastly, how transport justice can be measured. According to Verlinghieri & Schwanen (2020: 2) nonlinearization, increase of urbanization, the climate emergency and most recently, the COVID-19 pandemic, have positioned questions of transport justice in the heart of broadened discussions around fairness and justice.

The underlying theoretical arguments for **why the concept of justice should be applied to urban transportation systems** and investments have been elaborated in literature as following. Mullen et al. (2014: 3f) point out that the basis for demanding transport justice is the notion that each person has equal moral value. Therefore, governance and policy should be designed to show **equal concern for each person**. Equal concern requires access to means of conducting the projects and activities that matter to people. Thus, it goes beyond the idea that people should not be excluded from accessing means or conducting activities. It rather implies distributive policies that facilitate conducting activities and projects (ibid: 4).

Practically applied to transportation**,** the following arguments have been exposed. Transport improvements and investments inevitable lead to an uneven distribution of transport benefits (Martens et al., 2012: 684), and **benefits of existing transport infrastructure and services are usually not distributed evenly amongst population groups** (Foth et al., 2013: 1), eventually increasing the risk of enforcing social deprivation and thus threatening social sustainability on the long term. This is especially relevant when considering that most of the transport infrastructure is publicly funded. Due to this relation, government intervention is needed (Martens et al., 2012: 688), with urban and transport planning offering **corrective policies**. These should be based on knowledge and understanding of possible inequalities within a city (Duranton & Guerra, 2016: 5). In today's practice, mobility and transport, contrary to education or health, cannot be considered as a substantial part of modern welfare states. Albeit states do spend an important share of their budget on transport infrastructure and services, it is primarily economic efficiency that leads spending rather than consideration of welfare and equity (Jeekel & Martens, 217: 8).

The **questions on how to assess justice in the transportation field is not trivial to answe**r. Some authors, such as Martens et al. (2012) or Nazari Adli & Donavan (2018), have based their theoretical framework on the works of Michael Walzer (1983) and John Rawls (1971). Walzer, in his work "*Spheres of Justice"* conceptualizes society as a distributive community in which produced goods are shared, divided, and exchanged in a specific way according to their social meaning (Walzer, 1983: 6f). He later develops "distributive spheres", arguing that goods, to which society does not ascribe distinctive social meanings, such as necklaces or luxury yachts, can be distributed by the market. In contrast, goods with distinctive meaning should be taken out of the sphere of free exchange (*ibid*: 21f). Based on this rationale, Martens et al. (2012: 685) argue that benefits of transportation, having a distinct social meaning, should be distributed through a principle distinct from market exchange. Nazari Adli & Donavan (2018) base their work on John Rawl's "*Theory of Justice*". One of the main arguments is that policy settings should be based on how they affect the least fortunate (Rawl, 1971; cited after Nazari Adli & Donavan, 2018: 57).

After examining different arguments for implementing justice theoretic approaches to the field of transportation research and planning, the following paragraphs will outline which aspects are comprised within the concept of transport justice. Firstly, it must be said that when analyzing transport justice, focus can be laid either on the transport benefits or on the burdens. According to Martens et al. (2012: 686) the distribution of transport-related burdens has received more attention in literature.

Gössling (2016: 1), addressing both transport benefits and burdens, identifies "**transport injustices**" within three dimensions: (1) **exposure to traffic risks and pollutants** (accident risks, distress, noise, harmful substances, climate change), (2) **distribution of space** (e.g., among transport modes) and (3) **the valuation of time**. Exposure to traffic risks and pollutants primarily refers to the negative externalities of transportation systems, such as environmental degradation, air pollution or accident risks.

Looking at the distribution of **transport benefits** most authors agree that **accessibility to destinations** is the main factor to look at, as its measurement comprises both the aspect of distribution of space (location of destinations, allocation of space for infrastructures) and the aspect of time through in most cases considering travel times. According to Mullen et al. (2014: 5) lack of access, so a lack of transport benefits, should also be understood as a risk in this context. Jeekel and Martens (2017: 53) state that they consider equity in transport to be primarily – albeit not only – concerned with the level of accessibility that a person may experience within a transport-land-use system. They further compare the equity principles applied to other pillars of modern welfare states, such as housing, education or health care to the transport sector, posing the question which equity principles could be derived for the transportation sector.

Gössling (2016: 1) argues that current transportation systems are characterized by injustice, as they tend to favor private motorized transport, accepting social and environmental burdens to society. He lays stress on enhancing public transport, cycling, and walking in order to create a more just urban transport system. "*The identification and acknowledgement of injustices and inequalities in contemporary transport systems can inspire more sustainable designs and justify policies seeking to establish more sustainable transport systems*." (Gössling, 2016: 3).

Lucas (2006: 803) points out that focus should also strongly be laid upon **mode-related equity.** Generally, there have been considerable differences in the political treatment of urban transport modes and aspects of equity and the overall risks on society were hardly considered in the past (Gössling, 2016: 5). In this context, motorized traffic has not only been given the biggest amount of urban area, both for circulating and parkin, but also is responsible for a big share of risks, including accidents, emissions, or noise (Gössling, 2016: 5f; Lucas, 2006: 803).

Summing up, the state-of-the-art on transport justice seems as follows. There is a broad body of literature on the theoretical approaches to transport justice, as well as a vast number of empirical studies on the disparities in terms of accessibility. However, little public and political debate has been happening about the equity underpinnings of transportation planning and policies (Jeekel & Martens, 2017: 11).

2.1.3. Implementation of transport justice

After having discussed some of the underlying arguments of the transport justice discussion, this chapter aims at offering an overview of **what transport justice could subsequently mean**, both in theory and in practice.

Several approaches have been developed in literature to theoretically define what transport justice could mean. According to Neutens et al. (2010: 1621) **equity refers to a situation of no systematic differences in accessibility** values between groups of people. Those groups may be defined based on spatial location, like it is the case in the course of this thesis, or other classification schemes such as income groups, age or gender. According to Foth et al. (2013: 1), transportation benefits, with accessibility being the most important benefit, can intuitively be quantified as "*either a high number of destinations reachable within a certain threshold or a short travel time to preferred destinations*". Access should be distributed equally irrespective of the difference between those people, unless convincing arguments can be provided for another way of distribution (Martens et al. 2012: 687).

However, there are **several restrictive factors to this ideal**. Equal distribution in the sense that everyone in every location gets same level of access in space is impossible to achieve. Space by its nature its divided into center and periphery. Centers will always develop as consequences of advantages of spatial proximity (Martens et al. 2012: 687). Transport and urban policies can only correct the differences between center and periphery up to a certain degree. Therefore, **a certain level of differences could be acceptable as long as a "basic" level of access is guaranteed** (Martens et al. 2012: 688). Gössling (2016: 2) consequently argues that transport justice should **represent a political and societal goal**.

This **poses the question of which approach to equity in the transport field could be used**. The approach needs to be more realistic and allow to define a range of acceptable distribution (Foth et al. 2013: 3). According to Martens et al. (2012: 684) there is no clear general definition, neither in theory nor in practice, on what constitutes a fair distribution of transport benefits. They thus propose to assess equity in the transportation field **through distributive principles** rather than through the strict principal of equality. The positive aspect is that it **does not necessarily demand for uniformity** (Martens et al. 2012: 688).

The approach Martens et al. (2012: 688) propose is, amongst other methods reviewed in their paper, maximizing the average access level with a range constraint. They refer to this method as "**maximax**", following the aim of maximizing the average while observing the maximum gap. The height of the floor constraint in relation to the maximal level of access experiences by the most accessible community should be defined. Alternatives considering the **distributional aspect** would be maximizing average access levels with a floor constraint for the minimum or maximizing the lowest level of access. The last one, aiming at benefitting the worst-off groups from the transport perspective, seems not applicable to the authors (ibid). Foth et al. (2013: 3) on the other side, put public transit into the focus of equitable distribution of transportation benefits. They depart from the demand of first maintaining a decent level of benefits for the most socially disadvantaged groups and then maximizing the average for all, thus narrowing the gap.

However, there is also criticism to those proposals**. Nazari Adli & Donavan** (2018: 57) argue that the maximax principle, proposed by Martens et al. (2012) is not suitable as an indicator for equity. The argue that the Pearson correlation coefficient should be used to express justice test results (ibid: 69). They also state, that **major public transport investments should ideally disproportionately benefit the less well-off in order to be equitable** (ibid: 74; Martens et al. 2012: 689).

Moreover, transport justice can be analyzed from different perspectives. Martens et al. (2012: 688f) propose differing between **mode-related and space-related equity**. Figure 1 sketches this distinction, although the authors only address car-based and transit-based access in this figure, it is likewise true for other transport modes. Access levels can either be compared between neighborhoods for the same mode (1) or between modes for the same neighborhoods (2). Within this thesis both approaches have been included in the comparison of accessibility levels between neighborhoods. However, in addition, an attempt to compare accessibility levels across modes and areas is undertaken (see chapter 5), as this can give a general notion of the unequal distribution of transport benefits.

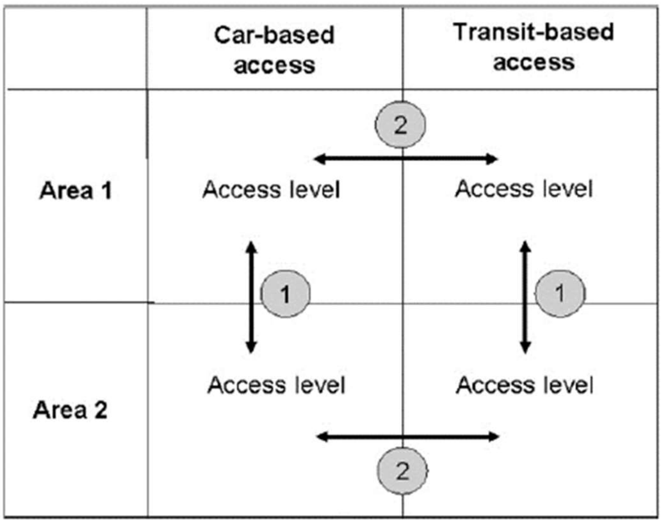

Figure 1: Different comparison types for accessibility levels (Martens et al., 2012).

Whilst Martens et al. (2012: 688) pose the question whether equality of access should be guaranteed irrespective of people's mode availability, other authors have also called attention to the importance of mode availability when evaluating accessibility. This is highly relevant due to the modal mismatch, which refers to the difficulty to reach desired destinations without a car (Foth et al., 2013: 2). Lucas (2006: 803) points out the importance of fostering and improving public transport. Evidence from their study conducted in UK showed that car availability in households was one of the most significant difference in people's ability to participate in social life.

Finally, there are also some **approaches from planning practice** that aim at defining equity principles for transport. For example, the Sound Transit in Seattle compared the percentage of benefits, including travel time savings and job accessibility, to the percentage of low-income population (considering standard deviation). This approach takes proportionality as criterion to assess the fairness of benefit distributions (Martens et al. 2012: 691f). Others compare the plan scenario to a no-plan scenario, regarding accessibility to jobs for low-income neighborhoods (Martens et al. 2012: 692).

It is, however, not only important to assess existing systems and check for fairness of investments in infrastructure. Also, the question of how will benefit from developments such as autonomous vehicles and Mobility-as-a-Service (MaaS) is of primary importance. Or if such and other developments may even contribute to changing the discourses about rights, responsibilities, and opportunities with respect to transport and mobility (Verlinghieri & Schwanen, 2020: 102 799).

2.2. Accessibility as main transport benefit

2.2.1. Definition

The concept of accessibility has been used in a number of scientific fields, amongst them transport planning, urban planning and geography and thus plays an important role in policy making (Geurs & van Wee 2004: 127). The term of accessibility has first been introduced as a concept for measuring transport benefits by Hansen in 1959. The author defined accessibility as the *potential* of opportunities for interaction, thus being **a measure of the intensity of the possibility of interaction** (Hansen, 1959: 73). In other words, accessibility can be defined as "***the ability to reach desired goods, services, and destinations – collectively, opportunities"*** (Litman, 2003: 29) and it is in fact the reason why people undertake trips in most cases (Boisjoly & El-Geneidy, 2017: 39). Geurs & van Wee (2004: 128) define accessibility as "*the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)".* According to Geurs & Van Wee (2004: 128), accessibility measures are generally seen "*as indicators for the impact of land-use and transport development and policy plans on the functioning of the society in general."*

In literature, the terms "access" and "accessibility" are often used indiscriminately. However, Geurs & van Wee (2004: 128) suggest differing between the terms. The authors refer to "access" when talking about a person's perspective and to "accessibility" when using a location's perspective.

A clear **distinction between accessibility and potential mobility** must be made. Potential mobility is defined as "the ease with which a person can move through space" (Sager, 2005: 4), and the most typically used indicators to measure it, are travel speed or travel times. However, this concept largely omits the relevant interaction between land use system and the transport system. The question of what should be reached and how easily this should be possible is usually not raised in the context of potential mobility (Boisjoly & El-Geneidy, 2017: 38f).

Subsequently, most authors agree that the concept of **accessibility is the more suitable concept to reflect and measure transport benefits** (e.g., Boisjoly & El-Geneidy, 2017: 38; Jekeel & Martens, 2017: 1; Kenyon et al. 2002: 207; Martens et al., 2012: 687), since it is one of the most comprehensive measures to assess the complex performance of land use and transportation systems in a region (Boisjoly & El-Geneidy, 2017: 38). Following the definitions above, accessibility is largely contingent on the distribution of destinations in space (land use component) and the ability to move from one place to another (the transport component) (Geurs & Van Wee, 2004: 128).

Although the definition of accessibility is seemingly simple, the term involves considerable complexities when practically working with it (Gössling, 2016,5). The questions of *access to where* (which destinations should be considered?), *by which modes,* considering *which factors* etc. rapidly arise. The complexity, however, allows to implement accessibility as a parameter to reflect the social benefits of transportation networks (Boisjoly & El-Geneidy, 2017: 39). Thus, accessibility is understood to be closely related to distributional equality (Gössling, 2016: 5, Boisjoly & El-Geneidy: 39) and it is therefore used as the most important concept for the empirical part of this research.

2.2.2. Factors influencing accessibility

Accessibility, although playing an important role in policy making, is, according to Geurs & Van Wee (2004: 127) in many cases a misunderstood and poorly defined and poorly measured construct. It is thus important for this research to clearly understand the various components of accessibility. Four main types of components can be identified: **land-use, transportation, temporal and individual** (Boisjoly & El-Geneidy, 2017: 38; Geurs & van Wee, 2004: 128). Figure 2 (Geurs & Van Wee, 2004: 128) sketches the relations between the different components and gives an insight into the complexity of the concept of accessibility.

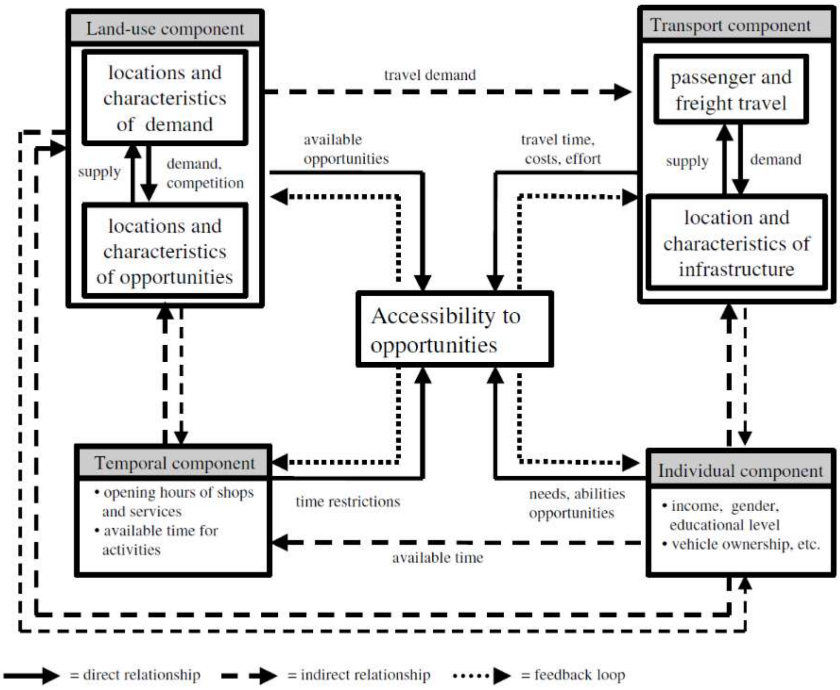

Figure 2: Components of Accessibility (Geurs & Van Wee, 2004).

The **land use component** is determined by the location of both origins (locations or areas for which accessibility ought to be defined) and destinations (the opportunities to be reached) (Geurs & van Wee, 2004: 128). The quantity and spatial distribution of activities within a city is a crucial factor when determining access to opportunities (Basso et al. 2020: 140). The land use component has direct influence on accessibility by determining the distance between origins and destinations. On the other hand, accessibility is an important amenity. Areas with high levels of accessibility are likely to attract people and services (Nazari Adli & Donovan, 2018: 57).

The **transport component** consists of the transport system, including built transport infrastructure, offered transport services, and the transport mode availability (Geurs & van Wee, 2004: 128). As marked in Figure 2, travel time, monetary costs, or other expressions of the effort it takes to overcome distance in space, are also included and influence accessibility to opportunities. However, as Durantón & Guerra (2016: 12) point out, there are further complications to consider about transportation. For example, traveler's decision to travel also affect the cost of mobility for others in the system. As capacity if infrastructure and services is restricted, an increase in the number of travelers may slow down travel for all. Also, additional time costs for finding a parking lot occur in reality but are seldom considered in any accessibility model.

The **temporal component** allows to take restrictive time factors into consideration. This could be opening hours of shops and services, availability of opportunities at different times of the day and individual's available time for participation in certain activities (Geurs & van Wee, 2004: 128).

Lastly, the **individual component** is probably the most multilayered and complex component to fully understand. It comprises individual abilities, such as the ability to navigate within a transport system, to access information or to use transport modes. Moreover, accessibility at individual level can be restricted by factors, such as physical or psychological condition, income and travel budget or car ownership (Geurs & van Wee, 2004: 128). The variety of possible constraints makes it difficult to adequately reflect individually perceived accessibility levels (Neutens et al. 2010: 1621ff).

Martens et al. (2012: 684) propose a slightly different classification of aspects accounting for accessibility. They define three main components: The **spatial component** (geographical location, built environment and distribution of land use or destinations to be reached), the **socioeconomic component** (income, population structure) and the **transport componen**t (mode availability). The temporal component is partially included in these components, e.g., by taking personal travel budget into account as part of the socioeconomic component.

Considering the mentioned components and all the aspects that could or rather should be included in the considerations when assessing accessibility for an individual (group) or an area, it is evident that measuring accessibility is not a trivial task. According to Geurs & van Wee (2004: 134) most theoretical shortcomings in literature are related to the exclusion of temporal and individual constraints. Nevertheless, it is regarded to be the indicator that best reflects the interplay between transportation system and land use, which is why numerous authors advocate for an increased inclusion of accessibility goals and indicators into plans and policies (e.g., Boisjoly et al., 2017; Foth et al., 2013; Martens et al., 2012).

2.2.3. The shift from mobility paradigm to accessibility planning

Transportation planning has emerged as an isolated field that initially only focused on mobility, which is defined by the *ease of moving* (Boisjoly & El-Geneidy, 2017: 39). The so-called mobility paradigm was based the evaluation of transport system performance on indicators such as ridership numbers, average travel speeds or travel times (Banister, 2008: 74; Foth et al. 2013: 1). Moreover, during the longer time of recent history, automotive predominancy in cities in North America, Europe and later also Asia led to a situation where transport planning was mainly concerned to follow the “predict and provide” principle, eventually leading to an increase in individual motorized transport (Gössling, 2016: 2).

This slowly started changing after accessibility was introduced as metrics for performance of land use and transportation interplay (Hansen, 1959). Several researchers have since than emphasized the need to include accessibility as an important indicator for social performance of urban transport systems (Boisjoly & El-Geneidy, 2017: 39). There is a general shift towards society-centric research on transport and mobility (Verlinghieri & Schwanen, 2020).

But what does accessibility planning or planning for accessibility refer to? According to Lucas (2006: 804) the key aim is to ensure that local decision-makers have improved information on the areas where accessibility is the poorest. Moreover, using accessibility as a main indicator for performance of land use and transport planning, it will allow to create more integrated and equitable processes (ibid: 808f). Pyrialakou et al. (2016: 253) argue that it will help to “*incorporate the notion of equity in transportation planning and decision making”.* Martens et al. (2012: 693) suggest that authorities should compare access levels across areas and modes in order to evaluate the outcomes of land use and transport policies from the social outcome perspective. Ideally, planning for accessibility would eventually provide all individuals with reasonable travel time to various destinations, while especially considering active and public transportation (Banister, 2008).

By now, accessibility has been introduced as evaluation metric for transportation planning in various countries. Namely in the UK and in Australia, attempts have been made to revise planning and policy perspectives to better account for the phenomenum of transport disadvantage (Pyrialakou, 2016: 252). The United Kingdom’s national government has established compulsory accessibility planning requirements, which’s implementation has been however criticized by Halden (2011: 14ff).

According to Boisjoly & El-Geneidy (2017: 40), accessibility is not yet a mature concept in planning and the paradigm shift from mobility to accessibility is far from complete. Also, Nazari Adli & Donavan (2018: 56) conclude that whereas the theoretical basis of justice questions in transport planning is well established, evidence suggests that justice-oriented thoughts have only limited influence on policies.

In transportation planning practice, distributional goals are rarely stated, or if they are – it is often unclear how they are to be evaluated (Martens et al. 2012: 684). Distribution of access between places and between modes is seldom considered explicitly. Durantón & Guerra (2016:5) point out that even when data are good, the politics of land use and transportation decisions rarely favor accessibility as an important policy outcome.

2.3. Measuring accessibility

The empirical part of this research relies substantially on the measurement of accessibility. It is the basis for identifying and addressing possible inequalities in the distribution of transport benefits. Neutens et al. (2010: 1621) point out that the specific accessibility measure, as well as the characteristics of the land-use and transport system, affect the extent to which accessibility measures are able to articulate equity. Durantón and Guerra (2016: 4) remark that measuring accessibility is both conceptually as well as empirically challenging. Whereas they point out measures that weigh accessibility indices by job type, time of day and distance to be more complicated yet more accurate, they say "*however, at its heart, accessibility is an individual concept*" (Durantón & Guerra, 2016: 4). The question of how to measure the complex concept of accessibility will be discussed in the following paragraphs.

A broad **variety of methods for measuring accessibility has been discussed in literature** (for a summary see Geurs & Van Wee, 2004 and Neutens et al. 2010). According to Geurs & Van Wee (2004: 137) literature on accessibility shows a **trend towards more complicated and disaggregated accessibility measures**. Efforts to improve calculations follow the aim to better reflect the complex concept of accessibility, but they simultaneously increase the difficulty level of interpretation. However, in order to effectuate the shift to accessibility led transport and land-use planning, it is inevitable to provide accessibility measures that are relatively easy to interpret for planners and policy makers (Bertolini et al. 2005: 2010; Geurs & Van Wee, 2004: 137).

Levinson & Wu (2020: 130) argue that with the availability of big data, standardized transit network representations in the General Transit Feed Specification (GTFS) format, open data and satellite imagery, amongst others, it is increasingly feasible to measure and monitor accessibility. Those data can systematically be mapped an analysed with geographic information systems (GIS), as most authors suggest (Pyrialakou et al., 2016: 256). General set-ups for such model will roughly be outlined in this chapter.

2.3.1. Place-based vs. person-based approaches

The basic differentiation of accessibility measures is to be made between the individual level and the location level. Those measures are referred to as **person-based and place-based measures** (Miller, 2005: 64ff; Boisjoly & El-Geneidy, 2017: 39f). The more frequently used measures in applied studies are location-based (e.g., Bunel & Tovar, 2014; Cheng & Bertolini, 2014; Huang et al., 2020; Levinson & Wu, 2020).

Person-based measures are the more appropriate to conceptualize people's ability to participate in activities, considering space-time constraints (individual time-budgets) and the nature of travel behavior, such as complex trip chains (Huang et al. 2020: 127). Evidence from an accessibility metrics comparison applied to city of Ghent (Belgium) prove the importance of taking into consideration the time for activity participation. In that context the authors were able to demonstrate, that location-based metrics could not capture the fact that approximately a quarter of the population was prevented from accessing government offices due to a temporal mismatch between opening hours and individual time budgets (Neutens et al. 2010: 1632). However, people-based methods demand large samples of individuals' activity information (Huang et al. 2020: 127, Neutens et al. 2010: 1617), making the methods less feasible to apply.

On the other hand, **"*Location-based metrics*** *typically account for the number of opportunities that can be reached from a specific location, based on the travel costs to destinations using a specific mode*" (Boisjoly & El-Geneidy, 2017: 39). Focus is thus laid upon the spatial and the transport component, although temporal fluctuations for services can and should be considered in the models (Boisjoly & El-Geneidy, 2017: 48). The individual component is sometimes included in location-based studies through stratifying population by socio-economic characteristics. Location-based metrics are less appropriate to articulate heterogeneity of accessibility for individual's (Neutens et al. 2010: 1621), but they provide a comprehensive measure of the performance of land use and transport system at the regional level.

The most commonly used location-based metrics are (1) the cumulative-opportunity measure and (2) the gravity-based measure. Other location-based metrics are discussed by Neutens et al. (2010).

(1) The ***cumulative-opportunity measure*** *only accounts for the opportunities that are within a specific predefined travel costs threshold.*

(2) *The* ***gravity-based measure*** *accounts for the number of all opportunities that can be reached from a specific location, discounting the cost of physical separation, most frequently through considering travel times* (Boisjoly & El-Geneidy, 2017: 39).

El-Geneidy & Levinson (2006: 6) point out that the cumulative opportunity measure is a basic and early developed, however still widely used method. It is simple to understand and calculate but creates an artificial distinction of valuable and non-valuable locations through boundaries set by the researcher (either distance in meters or travel time in minutes). The gravity-based measure is more complex in calculations, as it attempts to capture traveler's perception of closer opportunities are more desirable to reach than those located farther (Foth et al. 2013: 4).

Although literature several authors highlight the shortcomings of locations-based metrics with respect to reflecting individual life-realities and thus perceived accessibility, there are important arguments for applying a place-based measure for this master thesis.

- Firstly, the diversification of lifestyles leads to an increased difficulty of formulating well-defined travel needs, but rather result in dispersed travel patterns. When attempting to evaluate transport justice, those distinctive travel needs seem too difficult to capture (Martens et al. 2012, 688). As mentioned before, it is important to provide accessibility measures that are easy to both compute and understand.
- Secondly, data availability is an important constraint factor. Location-based accessibility measures can usually be calculated with readily available information on land-use (origins and destinations) and on factors of the transport component, such as transport networks and time schedules (Geurs et al. 2004: 137).
- Place-based measures and specifically the gravity-based measure, are measures of *potential accessibility* (Geurs et al. 2004: 133). It is about what could potentially happen, independent from who is living in the analyzed areas in the moment of undertaking the research.

Neutens et al. (2010: 1633) thus propose to choose the cumulative opportunity measure with opportunities being weighted by attractivity. Boisjoly & El-Geneidy (2017: 47) suggest to ideally include both gravity-based and cumulative opportunities metrics. Geurs et al. (2004: 137) further conclude that the interpretation of location-based measures can be improved by not primarily looking at absolute levels of accessibility, but by comparing accessibility across place, time or both place and time.

2.3.2. Location-based accessibility model – Operationalization

Ideally, accessibility measures should take all components mentioned previously and all elements within these components into account (see chapter 2.2.2). When using location-based accessibility measures the spatial and the transport component are given the most relevance. Most frequently, accessibility is calculated through making use of geographical information systems (GIS). The multiple parameters to the model that have to be chosen by the researcher (Pyrialakou et al., 2016: 256) will be presented in this section.

For the **spatial component** origins and destinations of the accessibility model must be clearly defined by the researcher. Firstly, the question of "*Where?*" must be clarified. **Where is accessibility measured**? Usually, space is divided into smaller units of geography, like for example a building block or statistical census units. Accessibility is to be measured for these units. If accessibility is not measured for a whole city area, the specific areas for analysis should be chosen carefully. Levinson and Wu (2020: 133) suggest person-weighting accessibility levels for the analyzed areas. Weighting by the number of people experiencing that access could help obtain a better aggregate measure, they argue.

In a next step, the opportunities to where accessibility is measured must be defined. The most used type of opportunities are jobs (e.g., Bunel & Tovar, 2014; Fan et al., 2012; Foth et al. 2013; Huang et al., 2020; Owen & Murphy, 2020; Wang & Chen, 2015). However, it enriches the outcomes of studies if additional destinations, such as municipal services, health facilities or recreational areas are included into the analysis (Boisjoly et al. 2017: 47; Murphy & Owen, 2020: 6). Commuting only accounts for a fraction of all trips undertaken.

Moreover, various authors suggest weighting opportunities by attractivity. For example, a municipal facility offering a broader range of services should be valued as more desirable to reach and thus given more weight. In the case of job accessibility, in most cases the number of jobs in a certain destination location is used as weighting factor (Foth et al. 2014: 4). However, if more detailed data is available, accessibility could ideally also be calculated for different categories of opportunities, reflecting the diversity of job opportunities (ibid; Cheng & Bertolini, 2013: 109).

Some authors furthermore argue that competition effects could be included in the model, as they may be more accurate when opportunities are discounted due to competition amongst them (Levinson & Wu 2019: 143). In the case of jobs for example, even if a job is available and reachable from a certain location, the degree up to which it should incorporate in the accessibility level could depend on the number of competitors that claim to form a match with it (Bunel & Tovar, 2014: 11).

The **transport component** is the second crucial part to the model applied for measuring accessibility. When building up the model, researcher must decide which transport modes are analyzed and compared amongst each other. Different aspects concerning the transport modes should be incorporated into the model to cover the transport component in the best feasible way (Geurs et al., 2004: 130). This includes **travel costs** with different transport modes (expressed either in travel time or monetary cost), but also service hours and frequencies for public transit. It is important to keep in mind that an increase of travel speed with different modes does not necessarily lead to higher accessibility, as for example for public transport waiting times at transport stops could still generate a longer trip to destinations (Owen & Murphy, 2020: 6).

When assessing accessibility to destinations, the **impedance** function used is of importance for the results. Impedance encompasses time, money cost and other travel related expenses that are needed to overcome distance between origins and destinations (Levinson & Wu, 2019: 133). Speaking for the model, it is a function which tries to translate the effort into reduced access. In many cases a negative exponential function is used to articulate impedance (El-Geneidy & Levinson, 2006: 7). Impedance functions used should be different depending on the transport mode affected. Much effort has been laid upon improving impedance functions to better express how increased travel time and monetary cost may reduce access for people. For example, Huang et al. (2020: 112ff) developed an impedance function specifically for the case of taxis.

Furthermore, accessibility measurement can be refined by including **individual and temporal components.** Trip affordability is another potentially important aspect that should ideally be included into the accessibility model. Boisjoly & El-Geneidy (2017: 47) argue that excluding the financial costs of travel can easily lead to an overestimation of accessibility, especially for low-income individuals. Relevant costs would be fares for public transport, fuel prices and taxes, but eventually also prices for parking. However, as El-Geneidy et al. (2016: 309) indicate, no studies have included the observed cost of travel time together with the fare.

If the model was to be more refined, further parameters expressing individual travel time budgets, complex travel chains and personal constraints would have to be incorporated. As mentioned before, this is usually preferably done in person-based accessibility measures, whereas location-based approaches largely fail to articulate those individual constraints (Cheng & Bertolini: 100). Geurs & Van Wee (2004: 134) indicate that more research is needed to include individual spatial-temporal constraint in accessibility studies. This would allow to balance theoretical shortcomings of currently used accessibility measures. However, "*Applying the full set of criteria would imply a level of complexity and detail that can probably never be achieved in practice*." (Geurs et al. 2004: 136).

Thus, most accessibility case studies rely on simplified models, that are nevertheless complex to calculate, represent and interpretate (Cheng & Bertolini: 100).

2.3.3. Restrictions to measuring accessibility

Although the concept of accessibility dates back to the 1950s, Levinson and Wu (2020: 149) sharply criticize the gap between theoretical and practical application of accessibility models. In theory, a measure of access can be constructed that includes all times-of-day, all types of destinations, considering every (perceived) cost and articulating personal unique preferences. However, in practice, most accessibility studies make use of a measure of access to jobs (and a few other locations in some cases), by only few modes (mostly car and transit), considering actual (but not perceived) travel times and it is only done for the average person or selected groups (Levinson and Wu, 2020: 149).

Conceptualizing and measuring urban accessibility is i challenging and it depends on limited data (Durantón & Guerra, 2016: 5). Levinson and Wu (2020: 149) argue that more accurate demographic, land use and transport related data would be necessary as a starter to reduce the gap between the theoretical ideal of an accessibility measure and the practical operationalization. To many methodological dimensions would complicate the empirical part immensely (Bunel & Tovar, 2014: 1324f) The following aspects are in most cases not directly incorporated into the model to assess accessibility:

- A broad range of **individual constraints** are not included into the model as this would either require additional research to generate needed information or be obliged to rely on assumptions. El-Geneidy and Levinson (2006: 2) even state that "*Individuals uniquely perceive accessibility based on their individual priorities in life.".* Studies aiming at better understanding of uneven mobilities (time budgets, physical or psychological constraints, mobility chains, etc.) could help improving the starting conditions for including such individual constraints into accessibility measures (Verlinghieri & Schwanen, 2020: 1f).
- Due to **availability** or complexity of **real-time data**, many aspects of **real travel times** cannot be fully reflected in the applied GIS-model. For public transport, estimation of access levels is possible thanks to the introduction of General Transit Feed Specification (GTFS), which is an internationally normed format first introduced by Google in 2011. However, real-time data including delays is hardly available, thus making it difficult to assess accessibility considering real conditions. For other modes, it is also challenging to include additional time needed for the travel in real life situations, for example through including congestion or time needed for finding a parking lot.

Concluding this theoretical chapter, a lot of effort has been done in the last decades to better understand the importance of accessibility as a main transport benefit and in the context of (urban) transport justice. Also, numerous scholars have worked on improving the different approaches to measure accessibility. However, due to the complexity of the concept of accessibility, most applied studies rely on rather simplified models to represent reality.

3. Vienna's urban development and transport network

This chapter aims at giving an overview over Vienna's urban development and at explaining the fundamentals of Vienna's urban structure and transport network, especially focusing on the aspects relevant for the realized analysis. Accessibility, and consecutively realized travel behavior, are heavily influenced by urban form (Durantón & Guerra, 2016: 15). Thus, it is important to understand which urban structures could significantly determine the accessibility experienced by individuals in different areas of the city.

First, a short outline of the historical development of the city and a rough description of the current urban form and the transport networks will be offered in chapter 3.1. For the historical overview, focus will be laid on the time starting from 19th century, as this time is crucial for Vienna's current form. Durantón & Guerra (ibid: 15) emphasize that "*the durability of urban structure and the persistence of patterns within cities*" have a number of important implications for the concept of accessibility, referring to the durability of built infrastructure, allocation of residential areas and centers development.

Secondly, in chapter 3.2 the key policies and plans relevant for transportation planning and urban planning will be presented. This is important to be able to offer recommendations for addressing inequalities in accessibility.

3.1. Urban development and urban structure in Vienna

Vienna, located in Central Europe and at the eastern foothills of the Alps, is the capital and largest city of the Republic of Austria and represents the economic, political, and cultural center of the country. The city of Vienna has a size of 414,9 km^2 and has a population of around 1.911.200 as of 2020 (Vienna City Administration, MA23, 2020a), thus accounting for a population density of 4606 inhabitants/km^2.

The city is divided into 23 administrative districts. Districts 1 to 9 together with the 20th district are regarded to be the inner districts (see Figure 3), with the 1st district being the historic center and the place where the Roman and later the medieval city developed. Districts 10 to 19 and 21 to 23 are the outer districts.

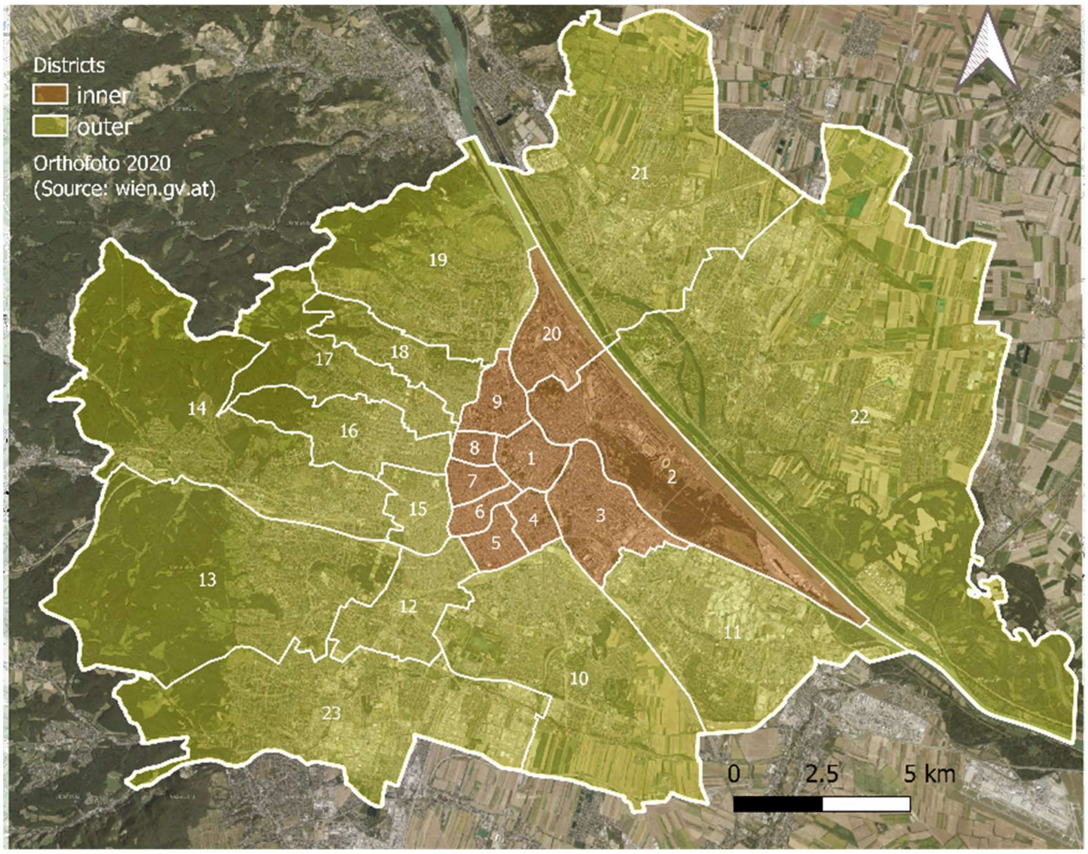

Figure 3: Inner and Outer Districts of Vienna (own figure based on MA41, 2021).

3.1.1. Historical urban development

The city of Vienna accounts for more than 2,000 years history and has developed based on the Roman legionary camp *Vindobona* in the first century AD (Wien Museum, 2021) to the important city it is today. The medieval and later baroque city developed on the former camp site and the historic centers dating back to those epochs still influence current urban form, also in today's suburbs (Pirhofer & Stimmer, 2007: 9).

Essential transformation to the urban form and size happened in the **19th century** when the town transformed into a multi-ethnic metropolis in the peak of the Austro-Hungarian Empire. Fueled through Industrialization, workforce from the Crown Lands of the monarchy kept arriving in the capital. Large infrastructure projects, such as the rail network (from the 1840s) were effectuated and significantly changed the city's physical and functional organization. Another relevant step was the **incorporation of the city's suburbs** into the municipality. Districts 2 to 9 were integrated in the 1850s and today's districts 11 to 19 were incorporated in the 1890s. The centers of those suburbs still form important sub-centers in today's urban pattern (Suitner, 2020: 9f).

One of the most relevant projects of Vienna's history, determining the urban form and transport connections as they area today, was the ***Ringstraße*** project in the midth 19th century. This magnificent boulevard surrounding today's first district replaced the former fortifications and is characteristic for Vienna's image today. Amongst the many changes effectuated in the *Gründerzeit* ("founders' period"), a phase of economic growth from 1840 to the 1880s, also the former outer fortifications were torn down and the ***Gürtel***, a street surrounding the inner districts was constructed (Pirhofer & Stimmer, 2007: 13ff). It constitutes one of the most important transport connections today.

At the turn to the 20th century, reformist social ideas had already begun to settle. A phase of "municipal populism" started around 1890 to 1910, including the communalization of several privately operated infrastructures, such as electricity and the tram network (Suitner, 2020: 7ff). Ongoing growth had led to miserable living conditions demanded for social reforms (Pirhofer & Stimmer, 2007: 20). Simultaneously, imperial and industrial visions perdured and led to visionary plans, which focused on center development and transport planning (Suitner, 2020: 7).

However, plans were interrupted by World Wars I and II. Poverty and hardship during WWI was striking, as the city had lost its economic basis and had largely been cut off from food supply. In the interwar years from 1919 to 1934 a period of Municipal Socialism, known as the "*Red Vienna",* set in, initiating an important first phase of the social housing program (Matznetter, 2002: 270). This phase was set a rough end due to WWII and the Austro-fascist state (Suitner, 2020: 11f).

After WWII**,** social housing programs were restarted and destroyed parts of the city were re-erected, mostly sticking to former urban structures. New-built areas of the 1950s and 1960s started to be increasingly car-friendly (Pirhofer & Stimmer, 2007: 56). In the 1960s and 1970s Vienna experienced wealth-induced suburbanization and the emphasis of social housing shifted to north of the Danube River, today's 21st and 22nd district (Suitner, 2020: 13).

The construction of the subway system started in 1969, although the first line, today's line U4, had been implemented as "*Stadtbahn*" (elevated city railway) in 1898 and plans for the implementation of an underground system had already existed for decades. The Lines U1, U2 and U4 started operating between 1978 and 1981, when the construction of the lines U3 and U6 started parallelly. In the same period, much favor was given to motorized individual transport and plans were made that suggested to stop tramway traffic at *Ringstraße* in order to facilitate motorized traffic flow (Pirhofer & Stimmer, 2007: 40).

In the phase between the early **1970s and 2000**, Vienna shifted to a more comprehensive planning (Suitner, 2020: 14). Emphasis was laid on the **outskirts and creation of sub-centers**, as well as **modernization of run-down inner-city areas**. Moreover, ecological goals, preservatives measures, and the empowerment of civil society came into spotlight. In 1976 the first comprehensive urban development plan was launched (ibid). Simultaneously, inequality within the city increased. It was a phase of a balancing act between welfare planning, which Vienna had a long history of, and adopting a competitive development model. According to Suitner (2020: 7), post-war Vienna shifted "*from technocratic modernization to considerate communicative urban politics and strategic governance in a competitive globalized environment.*"

At the beginning of the **1990s** Vienna had a population of around 1,5 million inhabitants. After the dismantling of the Iron Curtain (1989) and the later accession of Austria to the European Union, the city began to develop rapidly, both in terms of population and of economy. The population has most notably increased since 2000 (MA18, 2014: 14). The competition-orientated planning of that period led to the realization of the first master-planned and privately developed large-scale project "*Donau City"*, with the intention to add a completely new business center to the city (Pirhofer & Stimmer, 2007: 53). This area is now home to the *Vienna International Center* (seat of the United Nations amongst others).

The dynamic growth since the 1990s facilitated a profound change to the city over the last decades (MA18, 2014: 13). While strategic management and thematically targeted development became predominant in the planning culture, the development and transport connections with the city parts north of the Danube River were of great importance to accommodate the increasing population (Pirhofer & Stimmer, 2007: 113).

The expansion of the European Union, especially the inclusion of Austria's neighbor states Czech Republic, Hungary, Slovakia, and Slovenia to the EU in 2004 created new preconditions regarding mobility and economic development (MA18, 2014: 14). Relevant projects of the last two decades include the realization of the "*Hauptbahnhof"* (Vienna main train station*),* allowing an uninterrupted train connection from West to East through the city, the development of big former railway stations into mixed quarters, and the development of *Seestadt Aspern*, one of the biggest current urban development projects in Europe. Moreover, from a transport perspective, the inclusion of the rapid-transit train (*S-Bahn)* into the logic of high-ranked municipal transport system contributed to the improvement of public transport.

At current state Vienna's population is further expected to increase, although at a slower pace than in the period between 2000 and 2015. The population in 2034 is projected to reach almost 2,05 mio. inhabitants (Vienna City Administration, MA23, 2020b). The increase of about 140.000 additional inhabitants and subsequently increase in traffic volume up to that year means that additional capacities in housing, the transport network and other services have to be created. This holds an important potential for giving attention to aspects of social justice, in urban and transport planning. According to the City Planning Department, urban expansion will be restricted to those areas where sufficient public transport exists or can be established in parallel development (MA18, 2015: 31).

3.1.2. Urban Structure at present

Vienna’s urban structure is characterized by densely built historic inner districts, a radial-concentric form and by extended green areas in the outskirts of the city. Figure 4 shows a map of Vienna, highlighting the most important transport axis (road and railway network), green spaces and water bodies. Moreover, a basic distinction of land use (including business zones) and central areas according to the “*Polycentric Development Concept”* (MA18, 2020), are displayed on the map. Jobs are largely concentrated around centers and central areas and in the business zones. As can be seen, there is a high density of central areas in proximity of the city center.

Characteristic for Vienna’s urban forms are the two concentric ring streets, the *Ringstraße* around the 1st district (in red in figure 4), and the *Gürtel* around the inner districts. They both represent major axes for motorized individual transport, public transport, and cycling. Concerning the main road network, important connections take course form the city center in radial forms, connecting the city to the suburbs in the West, North and Northeast and South and Southeast area. The rail network, also displayed on the map, constitutes an important piece of not only international and regional transport, but also for travelling within the city. Further details on the transport network will be outlined in chapter 3.1.3.

The city of Vienna is crossed by the Danube River. Traditionally, the city has evolved south of the river and the development of the districts north of the Danube is rather recent, having gained in importance during the second half of the 20th century. Nowadays, the Danube along with the artificially mounted Danube Island, has become an important leisure and recreational area for inhabitants. Extensive green areas can be found at the Western and Southeastern borders of the city. The *Wienerwald* (“Vienna Woods”), which is recognized as UNESCO biosphere reserve since 2005 (BPWW, n.y.), is located west of the city and the National Park *Donauauen* is East of the built city area. Those areas are of great importance for the quality of life in the capital cities. Consecutively, possibilities for urban expansion or development in those directions are restricted due to the protection status of the natural areas.

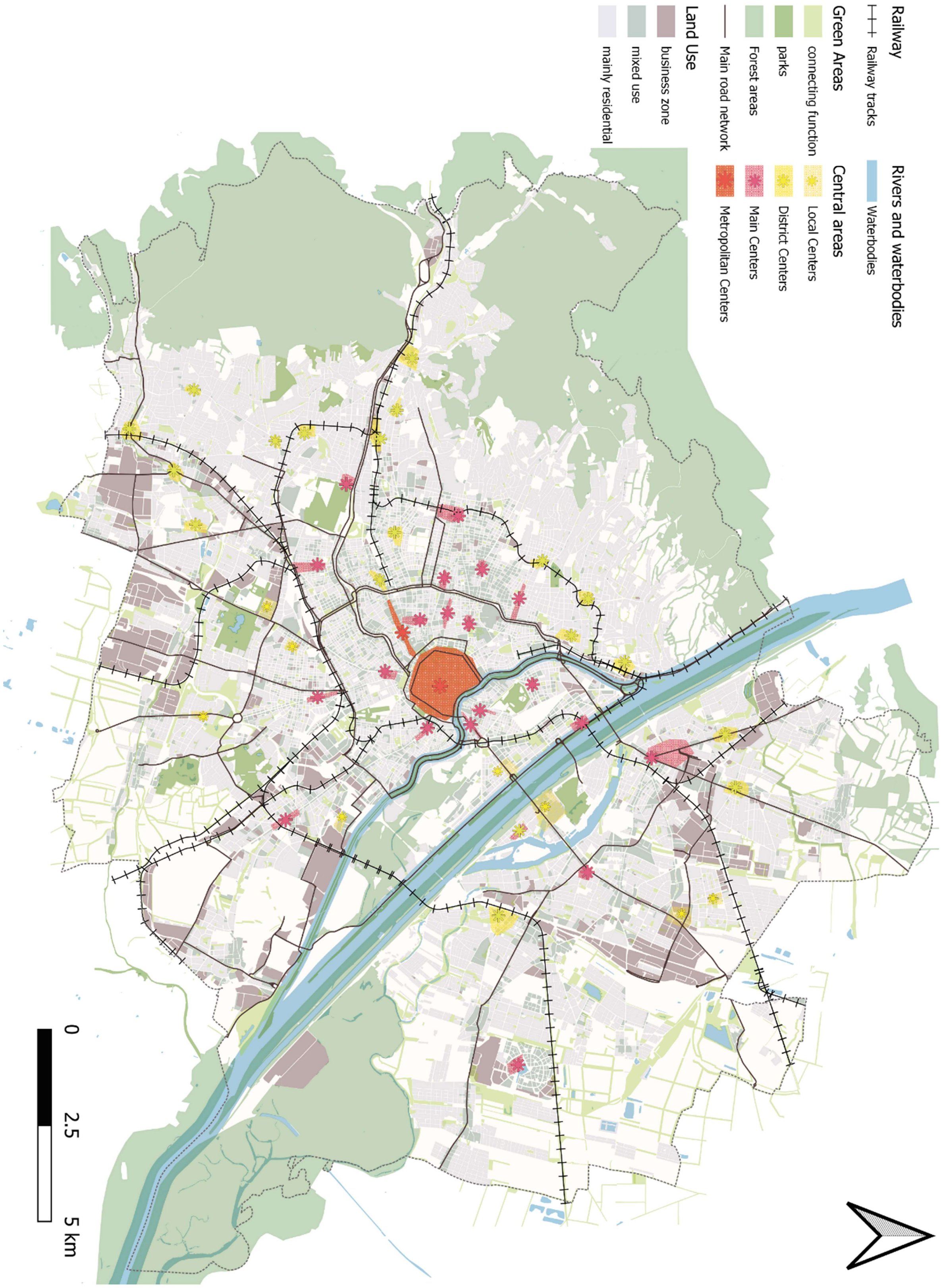

Figure 4: Structural Overview Map of Vienna (Own figure based on City of Vienna, 2021; MA18, 2020a; Wiener Linien, 2021).

Concerning land use and the distribution of centers and central areas throughout the city, the following remarks can be made. It is noticeable that a great density of main centers can be found around the 1st district that constitutes the historical center of the city. Despite the importance of the two metropolitan centers marked in the map, the main centers keep being highly relevant for the provision with daily goods, services and facilities of population. Many of the have emerged from former sub-urban villages that were integrated into the city in the 19th century. On the contrary, especially in the areas North of the Danube River, which have largely developed in the second half of the 20th century (MA18, 2019: 16), distances between centers tend to be bigger and there are less centers of higher rank. Business or industrial zones are mainly to be found in the South, North and East parts of the city. Represent important job agglomeration areas. On the contrary, for the inner city districts, more areas of mixed used can be found.

Overall, Vienna is well-known for a high quality of life and good performance in the areas of housing, public transport, and other relevant infrastructure services, such as waste management and drinking water management (MA18, 2016: 25). Although the city is highly livable, as well as affordable compared to other European capitals, increasing social differences are expected to become more pressuring (MA18, 2016: 13).

3.1.3. Characteristics of the Transport Network

The interplay between the land use system, which was roughly outlined in the two previous subchapters, and the transport system are the essential conditioners to accessibility. Following the previously outlined rationale of Geurs and Van Wee (2004: 128f), the transport component is conditioned by **infrastructure**, **offered transport services**, and **mode availability**. In the case of Vienna, various transport networks, as well as their interconnection, ought to be considered. This includes the streets network, which is essential for all means of transport, the public transport network, including railway, subway, tramway and busses, and designated cycling and walking infrastructure. This subchapter aims at giving an overview on Vienna's current transport system and currently planned improvements. It is thus an essential foundation for the modeling of recommendations.

Transport planning has been a main driver for urban planning since the 19th century. Regular traffic or transport concepts have been published for the city of Vienna since 1969 (MA18, 2015: 14) with roughly ten-years intervals. The newest strategic document is the *Urban Mobility Plan Vienna* (German: "*Fachkonzept Mobilität*")*,* which will be outlined in in chapter 3.2.2 Human-scale transport planning and the prioritization of eco-friendly means of transport, namely public transport, walking, and cycling are at the forefront of Vienna's official transport planning strategy. Shifting emphasis form private motorized transport to those modes is acknowledged to be favorable for a more equal distribution of transport benefits and burdens, both in the scientific discussion and in Viennese public discourse (Gössling, 2016: 1; MA18, 2014: 105).

Figure 5 displays the modal split[1] for Vienna in the years 1994, 2012 (before the preparation of the Urban Mobility Plan) and the aspired values for 2025 (MA18, 2015: 105). Although the city is vague about the exact proposed shares of public transport, walking and cycling, the overall aim is to increase the total share of those modes against that of motorized transport. Accordingly, current transport planning in Vienna lays or should lay emphasis on improvement of infrastructure and services of public transport, walking and cycling.

[1] The modal split represents the share of different transport modes in the distances travelled within a geographical unit

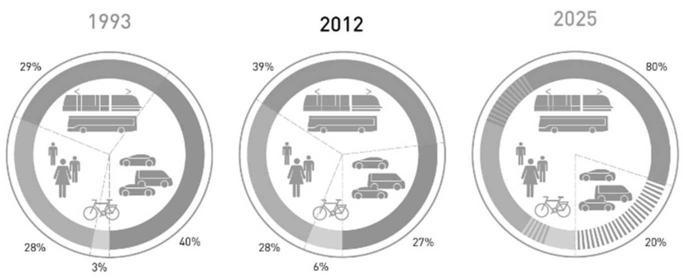

Figure 5: Modal Split 1993 and 2012 and Goal for 2025. (MA18, 2015).

Road infrastructure in Vienna can be regarded as well-established throughout all districts. Figure 6 shows the main roads, as well as local collector streets and other local roads within the municipal boundaries. The most important transport radial connections are streets connecting the city to the federal state of lower Austria and the two concentric transport axes: the "*Ringstraße*" surrounding the city center and the "*Gürtel*" around the inner city districts. A further important connection is along the Danube River.

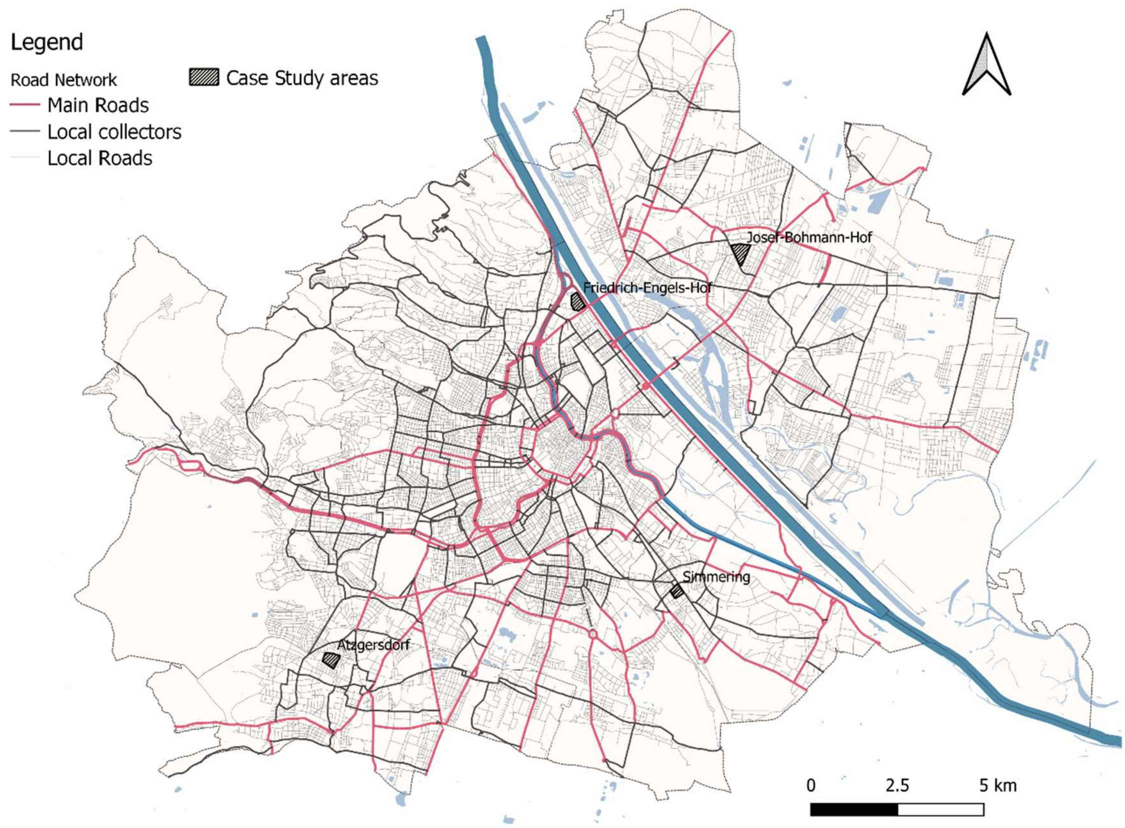

Figure 6: Vienna Road Network. (Own Figure based on City of Vienna, 2021).

Over the last years a continuous decline of motorized traffic volumes has been measured within the municipal limits of Vienna (see Figure 5), even in those districts where the resident population is increasing (Knoflacher et al., 2016: 16). In the Urban Mobility Plan, the city states that high-capacity roads are only to be built in the future if really needed and "*with sustainability in mind*" (MA18, 2014: 103). Nevertheless, the planned construction of a highway, passing the National Park Lobau in the east of the city, is currently a highly controversial topic in political and public discussion, being criticized for its expected environmental impact (ASFINAG, n.y.).

The **cycling infrastructure network** in Vienna comprises about 1.650 km at present, however different kinds of cycling infrastructure are included in this counting, thus the quality varies substantially. There are 168km of cycling paths separated from motorized transport, 169km of mixed paths for pedestrians and cyclists and 186km of painted buffer lanes. Moreover, cycling against the one-way is being introduced in most parts of the city (City of Vienna, n.y.). Although efforts are now increasing to expand the cycling network, there are still major gaps to be found and many cycling facilities are currently used to capacity limits or even beyond (MA18, 2014: 103). Figure 7 displays the status of cycling infrastructure, differentiating between built separation of bike infrastructure and those paths that are only marked, but not physically separated from motorized individual transport. Cycling infrastructure shows many gaps especially in the outer districts.

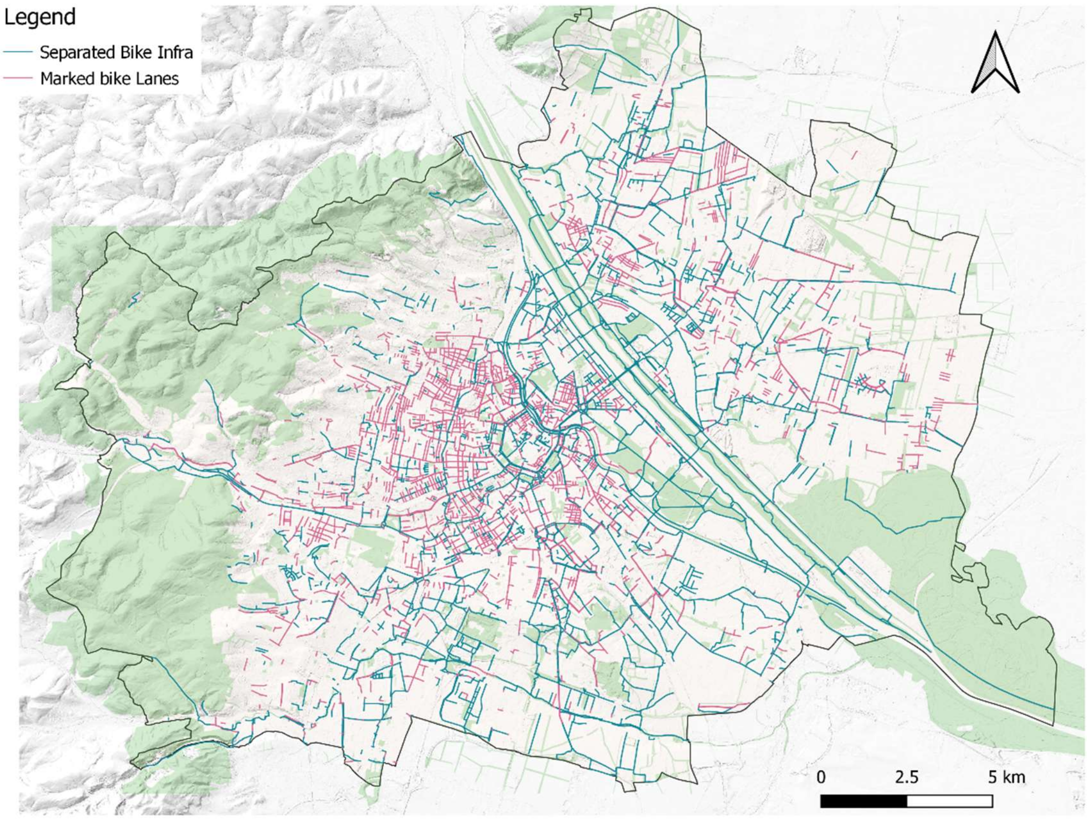

Figure 7: Vienna Cycling Network. (Own Figure based on City of Vienna, 2021).

Infrastructure for pedestrians is essential not only for the important share of daily trips that are effectuated by walking, but also for the acceptance of public transport. The walkability, referring to the safety and attractiveness of spaces for walking, is of major importance. Great emphasis is put on improving the conditions for pedestrians, including the 30km/h speed limit in extended parts of the city, and the progressive establishment of pedestrian zones (MA18, 2014: 35). It is important to mention that also in terms of tourism, being an important economic sector for the city of Vienna, walkability is highly important, as many of the important touristic areas are primarily visited by foot. However, due to the scope of this work, it is not possible to work on this topic in detail. Some insights on infrastructure for pedestrians will be given for the chosen case study areas.

The Viennese **public transport network** is well-established and according to surveys conducted by the city administration between 2003 and 2013, satisfaction with the public transport system is generally very high (MA18, 2015: 26). The five existing subway lines (see Figure 8) and the "S-Bahn" (suburban commuter train) are the main pillars of the network, which is complemented by capillary tram and bus networks (MA18, 2014: 105). In recent years, the lines U1 and U2 have been expanded. Currently, a new subway line (U5) is being constructed and the route of the U2 is being modified.

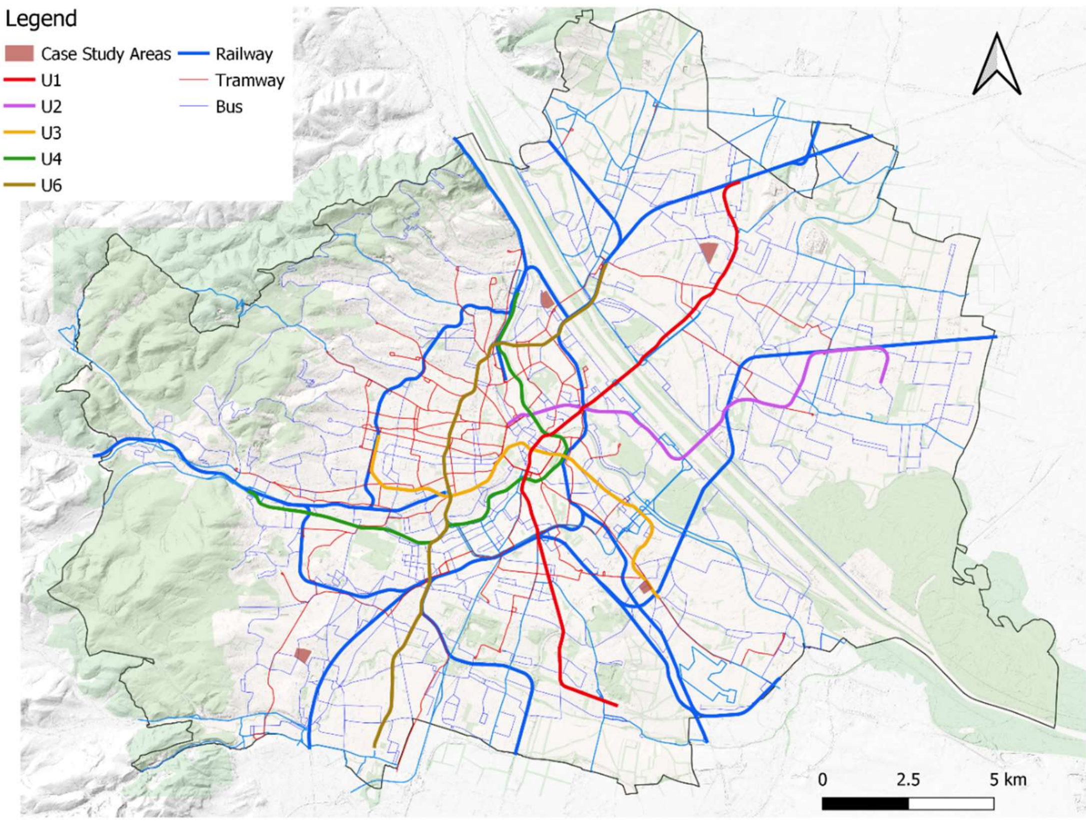

Figure 8: Vienna Public Transport Network. (Own Figure based on City of Vienna, 2021).

Apart from the major project of underground network expansion, the city plans to implement tram projects, specifically in new-built areas and in the outer districts, aiming at improving tangential public transport connections. Moreover, efforts to improve **multimodality** are made, for example through the implementation of "WienMobil Stations" (Wiener Linien, n.y.). Those are public transport stops, where additional services, such as bike- and carsharing, taxi or bike service stations, are provided.

As pointed out in the introduction of this subchapter, mobility and subsequently accessibility does not merely result from infrastructure, but also requires efficient organizational models and services (MA18, 2014: 111). Capacity and related bottlenecks can be important restraints for good accessibility. Moreover, **sharing services** are becoming increasingly relevant in Vienna's transport network and are important means of making different modes of transport available for a broader part of the population. There are several providers for free-floating car sharing services, as well as station-based car sharing systems (City of Vienna, 2021a). Also, different bicycle and e-scooter sharing services are available within the city area: the public station-based "*Citybike Wien*", operating 121 stations in all inner districts and parts of the outer districts, as well as neighborhood-based networks for cargo bikes and private operators of serviced bike rental. However, free-floating bike services have so far not been successful on the long term (Die Presse, 2018). On the other hand, free-floating e-Scooter sharing is on the rise in the city, with already five companies operating in this field (Widholm, 2021).

Another relevant aspect to consider is **mode availability and capacity of the different networks**. For motorized individual transport the ownership or availability of a vehicle and a driving license is relevant. Motorization rates in Vienna were of 377 cars per 1,000 inhabitants in 2019 for the whole city and ranges between 272 in the 15th district and 513 in the 23rd district (MA23, 2021). Martens et al. (2012: 687) point out that car availability is one of the most relevant factors that influence individual access levels. Although the total number of registered vehicles is increasing, car ownership rates in several districts are decreasing despite growing population. Ensuring accessibility without car is essential for transport justice, as many "disadvantaged groups", such as elderly and young population groups, persons with restricted mobility or low-income households, are likely to not have availability of cars (Gössling, 2016). However, mode availability is also crucial for other modes. For example, it is relevant to point out that the before-mentioned sharing services have **restricted operational areas**, which in many cases do not extend to the outer districts of Vienna.

The **capacity of the different transport networks** is a relevant factor influencing accessibility. As mentioned in this section, especially cycling infrastructure, but also some lines of the public transport face ridership numbers beyond the actual capacity limit. This is likely to reduce the actual levels of accessibility, however it is hard to reflect in the modelling and thus in the results of accessibility. It must be kept in mind as additional factor when addressing topics of distributional equity. Measures that partly already address those challenges are included in the strategic planning documents, that which be briefly summarized on the following pages.

3.2. Relevant strategic planning documents and policies

The currently most important strategic planning document for Vienna is the ***STEP 2025***. *"STEP"* is the acronym of the German title "**St**adt**e**ntwicklungs**p**lan", meaning "urban development plan". Moreover, in addition to this main document, the City Administration elaborated and published several **thematic concepts** on different urgent topics of urban development. Amongst them are the "**Urban Mobility Plan Vienna"** and the thematic concept "**Centers of urban life. Polycentric Vienna"** focusing on center development and urban structure. Moreover, there is the framework strategy "**Smart City Wien**", published in 2014 (MA18, 2016). This strategy has resource preservation as a primary goal and thus also addresses the sectors of mobility and infrastructure, which are crucial for the levels of accessibility. The key goals and conclusions of these documents will be summed up in the following pages, as they are highly relevant for giving recommendations on accessibility.

3.2.1. Urban Development Plan (*STEP2025*)

The current Urban Development Plan *STEP2025* was adopted by the Vienna City Council in June 2014. The title refers to the aspired time horizon, the year 2025, for accomplishing the visions and goals from the strategic paper. The aim of the *STEP2025* is to offer a development direction, not only for public administration, but also for other entities effectuating influence on the urban shape and ideally co-operating with the public sector (MA 18, 2014).

The *STEP2025* is subdivided into four main chapters, with the first being an introductory section. The second chapter "*Building the future"*, deals with renewal of the built city, urban growth and development of centers and underused areas. The following third chapter "*Reaching beyond its borders"* is concerned with Vienna's role as business and research hub and with the links within the metropolitan region. The fourth chapter "*Networking the city"* thematizes urban mobility, green spaces and social infrastructure in a growing city.

In relation to transport justice, it is noteworthy that already in the first stated objective of maintaining Vienna as a liveable city, social equity and the goal to "*safeguard a good social mix"* ibid: 9) is mentioned. Mixed urban quarters are seen as prerequisite for a liveable city. In fact, less separation of land usages is likely to be beneficial to a more equitable distribution, as goods and services might be more accessible for broader groups of population (Kenyon et al., 2002: 207).

The second chapter contains statements on development of built and new areas that would heavily influence the distribution of accessibility to opportunities throughout the city. Much emphasis is laid on polycentric development (MA18, 2014: 63ff) and on multifunctionality of centers (ibid: 61f). Whereas built-up parts of the city are targeted for improvement of open spaces, social facilities and mobility offerings, the city highlights that peripheral locations are to be brought "closer to the city", setting adequate public transport as prerequisite for any further expansion (ibid: 35ff).

Chapter 3, focusing on regional and international connections also lays emphasis on job creation and location, which will later be relevant in the analysis of job accessibility. The strategic document outlines that the city needs both inner-city and peripheral office and commercial enterprise locations, the latter with excellent transport links (ibid: 75). Again, much focus is laid on linkage of locations to public transport.

Chapter 4, which is the most relevant chapter in this research context, deals, amongst others, with mobility and transport. Departing from the forecast that population, workforce and consequently travel demand will increase until 2025, the *STEP2025* aims at not only expanding transport capacities, but also at significantly changing the city's modal split towards more environmentally friendly modes, including public transport, cycling and walking (ibid: 102f). Clear priority is given to "*enabling mobility without car ownership*", enhancing multimodality and upgrading public transport. According to Gössling (2016: 1) dethatching from private motorized transport is crucial to render urban transport systems more just in terms of distributional questions.

Accessibility, the ease of reaching destinations, is not directly addressed in the *STEP2025*. The social implications of transport are however shortly addressed by stating that future urban mobility policy ought to be "*not only ecologically, but also economically and socially acceptable and hence sustainable*" (MA18, 2014: 105). According to the document, the declared goals is "*to ensure mobility for all citizens irrespective of their income, social position and life situation.*" (ibid). As criticized by Boisjoly et al. (2017: 38f), amongst others, the concept of mobility (the ease of moving) seems to be prioritized above accessibility. This is reflected in the goals and indicators mentioned for transport. Whereas the "*systematic acceleration of public transport*" (MA18, 2014: 107), with speed being a typical mobility indicator (Boisjoly et al., 2017: 39), no goal in this chapter directly addresses people's ability to reach (certain) destinations.

Summing up, the *STEP2025* sets positive signs towards including aspects of social justice in the future urban mobility system. When it comes to mobility goals, accessibility as such is not addressed. However, many proposed priorities, such as enabling mobility without car ownership by prioritizing public transport and facilitating multimodal trips, might contribute to an overall increase of accessibility and to balancing possible gaps of accessibility for population with and without car ownership. The *Urban Mobility Plan* presented in the following subchapter offers more detailed information.

3.2.2. Urban Mobility Plan Vienna

The “Urban Mobility Plan Vienna” (German title: “*Fachkonzept Mobilität*”) is a thematic concept directly linked to the *STEP2025*. It specifies goals and measures related to transport and mobility. Preparatory works started in 2012, after the evaluation of the previous *Transport Master Plan 2003* (MA18, 2015: 109). According to the Sustainable Urban Mobility Plan (SUMP) guidelines provided by the European Commission (European Commission, n.y.), the urban mobility plan was elaborated with a participatory approach. Stakeholders were involved during the entire planning process (MA18, 2015: 14). The strategic concept was adopted by the Vienna City Council shortly after the *STEP2025*, in December 2014 and published the following year.

According to the **strategic framework** presented, the objective for **future mobility services** in the city of Vienna is that they are **fair**, healthy, compact, eco-friendly, robust in relation to climate change and efficient in terms of energy (ibid: 19ff). It is to be highlighted that “fairness” is named first amongst those objectives. The concept mainly links fairness to the allocation of public space to different modes of transport and to affordability, namely in terms of monetary cost of public transport. The main performance indicator in this context is designated to be the sum of spaces for cycling, walking and public transport in urban conversion and renewal projects. This is based on the **outlined assumption that equitable access to mobility (!) can only be ensured by other modes of transport than the private car** (ibid: 13). However, Boisjoly et al. (2017: 47) point out that, although one of the most commonly used metrics in urban accessibility plans, **access to public transport or to mobility does not directly address the ease of reaching urban opportunities**.

A series of **goals** are defined in the mission statement (MA18, 2014: 10). They are laying focus on and expanding **public transport**, favoring **cycling and walking**, facilitating **multimodal transport** and focusing on **sharing solutions**. Moreover, **mobility partnerships** ought to be established with neighboring municipalities in the region and **commercial transport** within the city should be organized in a more efficient way. Similar to the *STEP2025*, the *Urban Mobility Plan* highlights the **importance of a compact urban structure and polycentric development** for **future mobility** (ibid: 31f). This reflects the influence of the land-use component, the allocation of origins and destinations, mentioned in literature (e.g., Geurs & Van Wee, 2004: 128).

When it comes to **tangible objectives and indicators**, the concept of access is only mentioned once: The “Access to public transport stops” is indicated as percentage of the population with an underground or suburban train stop located 500m or less form home or another public transport 300m or less from home (ibid: 26). As mentioned previously, this is a typical indicator for mobility, but not suitable to assess accessibility, which is the main transport benefit. No objectives or indicators are formulated that directly address distributional questions of transport benefits. The concept of access is only mentioned in the context of access to mobility services, to information and to (multimodal) stops.

Nevertheless, the **equity aspect** is mentioned a few times throughout the document, starting with the statement "*Sustainable and equitable mobility is an essential element of the high quality of life that characterizes the city." (*MA18, 2015: 13). The only explanation given on social equity in the transport field refers to allocation of public space to different transport modes (ibid: 39). This does, as has been demonstrated in chapter 2, not reflect many relevant aspects of transport justice. Equity can be said to be used as a buzzword in this case.

It is however outstanding and worth mentioning that all measures in the urban mobility plan were subjected to a **gender and diversity fairness check** (ibid: 113f). Using a procedure based on gender-sensitive (transport) planning, the goal was to evaluate the impact of the plan's proposed measures on groups with special mobility needs. These could be, amongst others, young persons, persons with restricted mobility, persons affected by poverty, caregivers, commuters and persons unfamiliar with technology (ibid: 114). Having this approach in the process of plan making is praiseworthy.

In conclusion, the efforts that have been undertaken to tackle social aspects of mobility in the *Urban Mobility Plan* are to be highlighted. The terms "equity" and "fair" are used in this context, however they are *a)* not understood in a similar way as in transport justice literature (see chapter 2) and *b)* no adequate performance indicators are defined. Although many measures are likely to contribute to improvement of overall accessibility, as car-free mobility is a primary goal, the next urban mobility plan ought to include accessibility as a performance indicator for the interplay of transport system and land use in Vienna.

3.2.3. Thematic concept on Polycentric Development

Similar to the urban mobility plan, the thematic "*Polycentric Development concept*" (german title: "*Fanchkonzept Mittelpunkte des städtischen Lebens")* is linked to the *STEP2025.* However, it was adopted by the Vienna City Council five years after publication of the urban development strategy, in December 2019 (MA18, 2020: 106). It thematizes **the development of existing and new centers** within the city, as well as the regulation of large-scale retail. It is a relevant basis for this research, as centers and central areas will be one category of destinations to be reached. According to the concept, centres are "*those places within the urban fabric, where urban life is bundled and concentrated. They are multifunctional spaces in the city and places of orientation and culture. They account for a great variety of functions and usages (such as retail & commerce, culture, social infrastructure, public space, jobs et* *cetera), supply and consumption offers, as well as opportunities for encounters and exchange"* (own translation according to MA18, 2020).

In the "*Polycentric Development concept*" centers are distinguished in three hierarchical categories (ibid: 30ff). They are denominated as (1) metropolitan centers, (2) main centers and (3) district centers or also local centers and fulfill different functions within the city (see Figure 9). Moreover, (4) new centers have been defined in the concept. However, those were not included in the analysis of accessibility (see chapter 4).

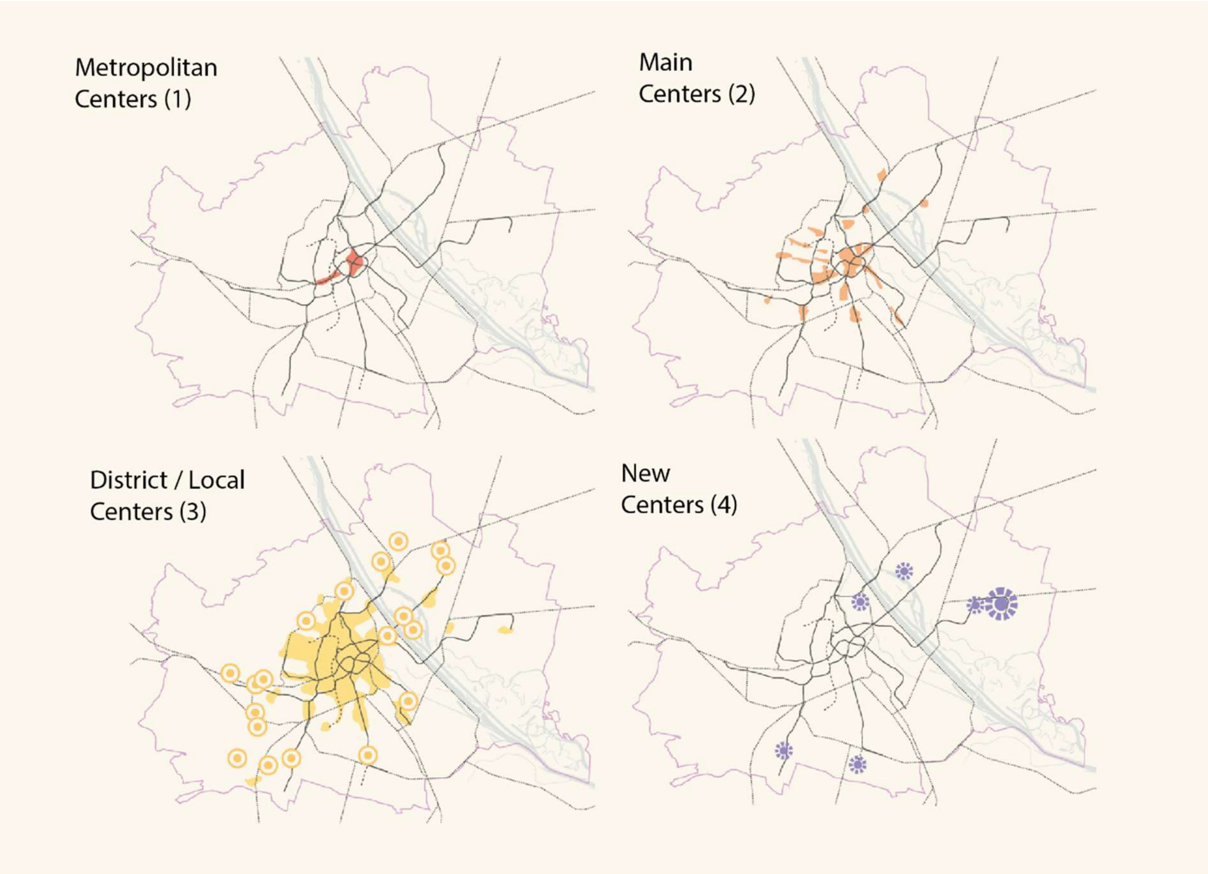

Figure 9: Centers and central areas according to the Polycentric Vienna Concept. (MA18, 2020).

In addition to a broad range of measures for design of public space and economic incentives, the "*Polycentric Development concept*" also lays stress on accessibility of the centers. Good access by public transport, cycling and walking is regarded to be a key driver for the development of centers and central areas (ibid: 68).

Summing up, the "*Polycentric Development concept*" offers a development path for centers in Vienna. This is essential for allocation of funding and for implementation of specific projects. The concept highlights the essential role of different ranked centers for the city's inhabitants and their ability to fully participate in social life, as well as the contribution to quality of life.

3.2.4. Other strategic documents

The above presented strategic documents are the most relevant planning documents for urban and transport planning in Vienna at current stage. However, there are other strategies on city level and superordinate level that condition decisions in transport planning. Some of them address social equity within mobility and transport. Brief overviews on Vienna's "*Smart City Wien"* strategy and the "*Austria's 2030 Mobility Master Plan*" will be given in the following.

The "***Smart City Wien***" document is a long-term framework strategy having the year 2050 as time horizon, published in 2014 (MA18, 2014: 110). The main objectives are resource preservation, strengthening of the economy, research and education and ensuring a top-level quality of life. The latter objective focuses on social inclusion amongst other (ibid: 72). The need for adequate participation in employment, as well as possibilities for individual development and the enhancement of strengthening social contacts and social skills is acknowledged to be essential for quality of life. Access to employment locations, as well as to cultural and educational facilities are regarded to be priorities of future development. Yet, neither the distribution of accessibility, nor transport justice is mentioned in any part of the strategy.

Finally, "***Austria's 2030 Mobility Master Plan"*** is the most recently published strategy (July 2021) and constitutes the national framework for transport planning. It succeeds the Transport Master Plan for Austria 2012. Although the new mobility master plan sets focus on reducing emissions and in this manner meeting the targets settled in the Paris Agreement, some remarks on social aspects of transport can be found. Firstly, the statement that "*Transport must be social, safe, environmentally friendly and efficient.*" is made right in the beginning of the document (bmk, 2021: 8). Secondly, it is highlighted that the mobility system ought to be "publicly accessible", in the sense of being affordable, safe and accessible for people with disabilities (*ibid*: 26).

As has been criticized before in the case of the Urban Mobility Plan for Vienna, the access to mobility is referred to, rather than access to opportunities (*ibid*: 52): *All people […] will have the same access to mobility regardless of their circumstances or where they live.*". Even if this captures a fundamental notion of equity for the transport sector, mobility is only the ease of moving through space, while access to destinations is the actual main benefit of improved mobility. However, it is undeniable that first approaches towards more social equity in transport are contemplated in the current strategy. The document even states that so far disadvantaged groups, due to reduced mobility, are now the main beneficiaries of the master plan, as guaranteed mobility without driver's license or owning a car comes into the foreground of efforts in passenger transport (*ibid)*.

4. Applied Methodology

This master thesis' empirical contribution encompasses the evaluation of accessibility to different destinations in Vienna by the three transport modes of public transport, bicycle, and car. Calculating comparable accessibility indices for specific areas is important to detect possible inequalities in the distributions of transport benefits within Vienna.

As most accessibility measures rely on travel time as the factor expressing the impedance to overcome distances in space (Boisjoly & El-Geneidy, 2017: 38), the time needed to travel from the chosen case study areas to jobs and centers has to be computed for different transport modes. This has been done through making use of a GIS-model including origins, destinations, and the respective transport networks. As already exposed in the initial chapter, the research was limited to analyze specific case study examples, as otherwise computation times would exceed the time scope for a master thesis. Thus, this chapter will firstly offer a short outline on how the case study areas in Vienna have been chosen (4.1). Thereafter, the detailed applied methodology for measuring accessibility will be exposed (4.2) and the approach for the evaluation and comparison of accessibility levels for deriving recommendations will be explained (4.3).

4.1. Choosing the case study areas in Vienna

The decision to effectuate the research as comparative case study was taken due to two major motivations. Firstly, choosing case study areas allows to thoroughly analyze the local circumstances that may influence accessibility levels. Instead of remaining polygons on the map, the case study areas will be characterized, and their specific context will be exposed.

Secondly, restricting the research to four case study areas was necessary to make the empirical part of the research feasible within given time and technical resources. The computation of travel-time matrices needed for the calculation of accessibility levels is time-intensive (Cheng & Bertolini, 2013: 105).

When conducting case study research, random sampling is not typically a viable approach when the number of cases is small (Seawright & Gerring, 2008: 1). Thus, the following **eligibility criteria** were previously defined to choose relevant areas for analysis.

- **Prevalent residential use:** Only areas with prevalent (not uniquely) residential use were taken into account for the selection of the case study areas. This is, because accessibility is analyzed in the context of transport justice and of course the question of how accessibility may affect individuals is most pressuring (Kenyon et al. 2002: 208).

- **Population density >130 inhabitants per hectare:** In order to tackle the phenomenon that people deliberately choose worse accessibility in order to profit from other advantages, such as proximity to forest area or owning an own garden, a minimum population density was taken as further criterion. The minimum value was fixed at 130 inhabitants per hectare, as this is the mean value for Vienna's built area (Vienna City Administration, 2020a).

- **Socioeconomic indicators:** In order to include socioeconomic indicators, the 2012 study "*Sozialraumatlas*" (Social environment atlas), commissioned by the City of Vienna, was taken as a basis (MA18 & ZSI, 2013). Within this study, all Viennese *Zählsprengel* (smallest statistical unit) were assigned to six socio-economic clusters, characterized by different factors, such as income, age structure, nationality, and employment status. The case study areas were chosen because they evidence high incidences of unemployment, incomes below average and partly high shares of residents with migration background or low educational levels. It has been important to include these aspects into the selection, as numerous authors point out that socio-economically disadvantaged households are more likely to experience lack of accessibility (Foth et al., 2013: 1).

- **Location**: Space by its very nature is divided into center and periphery and transport policies alone are unlikely to be able to correct the differences between center and periphery (Martens et al. 2012: 687). However, the concepts of center and periphery are not always easy to be defined and are, in reality, also not of binary nature. Thus, it was important to include a good mix of more peripheral and rather centrally located areas.

- **Existence of municipal housing:** Vienna has a long tradition of social housing provided by the municipal government and about 1,800 municipal housing complexes can be found in the city (Wiener Wohnen, 2019). As social housing is based on fundamental equity principles (Jeekel & Martins, 2017: 61), it is justifiable to look at accessibility in areas with municipal housing buildings in order to address transport inequalities.

Based on these criteria four case study areas have been selected from 13 areas that were initially taken into account. The **size and delimitations** of the chosen areas have been defined according to the statistical units of counting areas ("*Zählgebiete*", see City of Vienna, 2011). For statistical purposes, the city area is divided into 250 counting districts ("*Zählbezirke*") and further into 1,364 counting areas. As population density and socio-economic indicators were taken as criteria, most of the examples accounted for big building complexes from the 20th century.

4.1.1. Description of the Case study areas

Case study area 1, further referred to as "Simmering" in the upcoming chapters, is located in the south-east of the city of Vienna, in the outer district 11 called *Simmering*. Out of the four chosen case study areas, it is the second closest to the city center. The area is situated in direct proximity to the subcenter of Simmering and of the subway station with the same name. It is thus directly connected to high-ranked public transport. The area is of mixed use, with prevalent residential units of both municipal housing and private developments, but also an important share of retail. As can be seen in Figure 10, the built form within the case study area is quite diverse. It includes block perimeter and row development with green spaces in between, as well as a more massive structure, in which a small local shopping center is located.

Case study area 2, further called "Atzgersdorf" in the upcoming chapters, is located in the 23rd district, in the Southwest of Vienna. It is situated in a rather peripheral location in relation to the city center (1st district), but relatively close in terms of distance to the subcenters of *Atzgersdorf* and *Mauer*. Three complexes of social housing from the time period between 1958 and 1970 are located on the site. Altogether they provide more than 600 housing units (City of Vienna, 2021). Also detached houses can be found on the area and in the surroundings. Whereas the surrounding neighborhoods have a rather suburban character, this case study area's built form is strongly influenced by the row developments of the municipal housing blocks (see Figure 10).

Case study area 3 is situated north of the Danube River, in the 22nd district (*Donaustadt)*. As most of the case study area is occupied by the municipal housing complex from 1978 "*Josef-Bohmann-Hof"* (see Figure 10), the work will further refer to this case study area with the name of this built development, which alone accounts for 1,238 housing units (City of Vienna, 2021). The case study area is geographically quite distant form the city center, although the distance is shorter than for the case study area *Atzgersdorf.* The prevalent use is residential, but there is also a primary school, and some retail and gastronomy to be found within the case study area's boundaries.

Case study area 4, located at *Friedrich-Engels square* and thus denominated "Friedrich-Engels-Platz" in the course of this work, is the only case study area located in an inner district. Despite the centrality of the 20th district (*Brigittenau)* and the geographical proximity to Vienna's city center, the area has a rather peripheral location due to different barriers, which will be described more precisely in chapter 6.4. As seen in Figure 10, the case study area's built form is dominated by the municipal housing development *Friedrich-Engels-Hof* dating back to 1931 (City of Vienna, 2021).

More detailed information on the case study areas will be given in chapter 6, were the results of calculation of accessibility will be set into the respective areas' context.

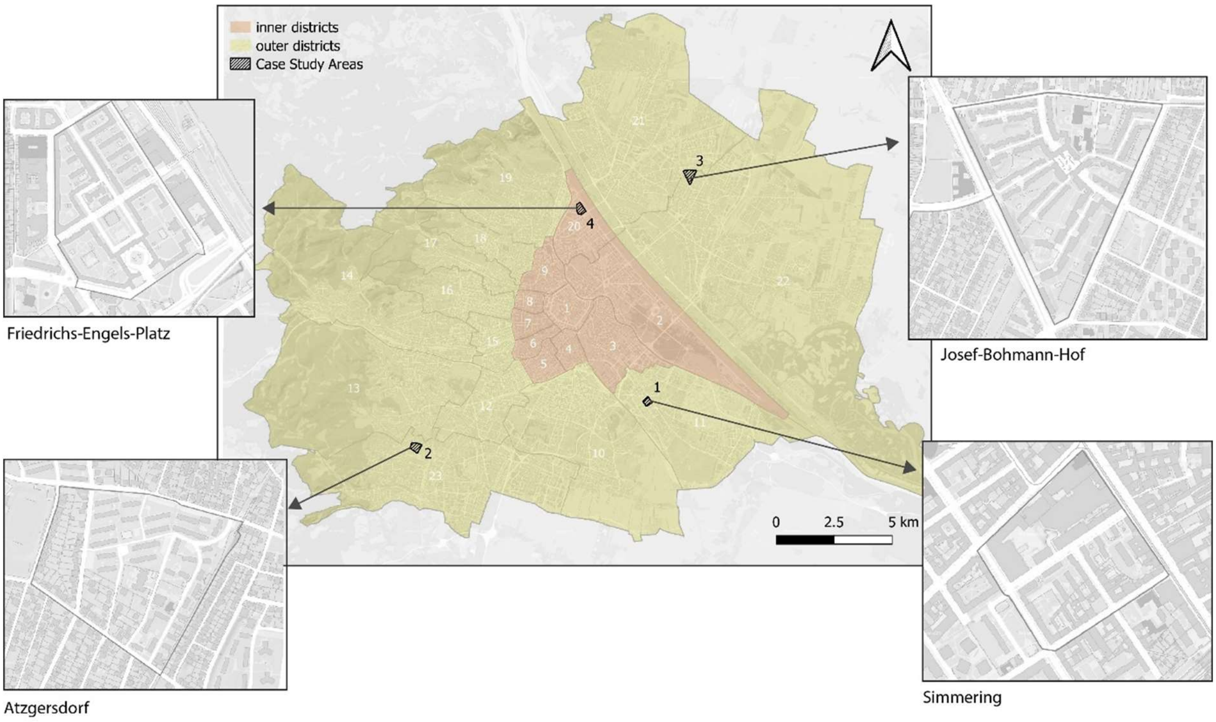

Figure 10: Location of the case study areas (Own figure based on City of Vienna, 2021).

4.2. Measuring Accessibility (GIS-Model)

After choosing the case study areas, the model for calculating travel times between origins and destinations has been built up in GIS, as it is the state of the art in most accessibility studies (Pyrialakou et al., 2016: 256). In order to evaluate accessibility levels, the following basic information has to be included: **origins** (=case study areas), **destinations** (opportunities to be reached; jobs and central areas), **transport network data** (transport infrastructure for different modes, public transport stops, etc.) and information on **time aspects**, including average travel **speed and time by mode**, as well as **public transport schedules and functioning hours**. All calculations have been restricted uniquely to the city of Vienna within its administrative boundaries for reasons of data availability.

Accessibility in this master thesis is measured from a **location-based perspective**, applying the **weighted-opportunities measure**, which is also referred to as gravity-based measure. This measure accounts for the number of all opportunities that can be reached from a specific starting location. Opportunities are weighted by their attractivity. Travel times are taken as impedance to discount for the physical separation of origins and destinations (Boisjoly & El-Geneidy, 2017: 39).

Accessibility to centers and central areas and jobs in the case of this research is calculated for **three transport modes**: public transport, cycling and motorized individual transport. For calculating **cycling and motorized individual transport** travel times, the Open Route Service plug-in for the open-source program QGIS has been used (see 4.2.3). It is a service provided by the *Heidelberg Institute of Geoinformation Technology* at Heidelberg University (heigit, n.y.). This Service is based on a network elaborated from Open Street map data and allows to create origin-destination-cost matrices. For **public transport**, a separate network has been modelled, making use of the GTFS (general transit feed specification) data provided by *Wiener Linien* (Viennese public transport operator) and *ÖBB* (Austrian railways operator). The modelling and calculation of origin-destination-cost-matrices has been done with the ArcGIS Pro Network Analyst Tool. The result of this step will be a time-distance matrix for each mode and area. **Walking has not been considered** in the analysis due to the nature of destinations chosen, except for covering the distance to and between public transport stops. This mode is usually examined in the context of accessibility to local services and supply. Micro-level factors, such as the built environment and quality of surroundings deserve a much more detailed analysis (Lucas et al. 2018: 623) that cannot be covered in this thesis.

4.2.1. Defining Origins: Case Study areas

Firstly, for the **origins**, a polygon layer was created with one polygon representing each case study area. Five random points have been generated with the "R*andom points inside polygon"* function in QGIS, applying it to the intersection of the case study area polygon and the buildings' polygons (see Figure 11). This is done with the idea of generating **different anticipated "starting points" from the case study areas**. This way, walking or driving distances within the polygons will be better considered. An average has been calculated for each area based on the results for every single starting point within the respective polygon. In addition to the above-described case study areas, two additional points in very central locations within the city of Vienna were included into the origins layer. Those were one point at *Karlsplatz* (south of the city center and an important transport hub) and at *Volkstheater* (west of the city center). Assuming that accessibility to opportunities from those points ought to be amongst the highest possible within the city, it will later allow to better compare differences in levels of accessibility. A total of 22 starting points were eventually considered for the calculation of travel times.

Figure 11: Creating the Origin Layer. (Screenshot of QGIS, with data from City of Vienna, 2021).

4.2.2. Defining Destinations: Jobs and Centers & Central Areas

Secondly, the **destinations** to be reached must be defined. For this study, the destinations taken into consideration for the calculation of accessibility levels are **jobs** on the one hand, and **centers and central areas** on the other hand.

Job Accessibility

The first group of destinations taken into consideration for the analysis of accessibility are **jobs.** Job accessibility is regarded to be one of the most important factors for social inclusion and subsequently the most commonly studied accessibility metrics (see chapter 2). For Vienna, data on workplace location and number of jobs at those workplace locations was only available from the **2011** census at the time of elaborating this thesis (Statistik Austria, 2014). New data will be published by *Statistik Austria,* the Austrian national statistical agency, in 2021, just after the completion of this work. Although the location of jobs in 2021 is likely to have changed since 2011, it is the best viable method to get a notion of job locations. The information on location of workplaces is available in a 250m per 250m raster and includes number of jobholders by sex and *OENACE* classification[2].

As mentioned previously, the weighted-opportunities measure has been applied to calculate accessibility levels. Thus, the destination points' attractivity had to be assessed beforehand. For not further complicating the methodology, in this case a higher number of jobs at a certain location (point in 250 x 250m raster cell) was assessed to be more attractive. Of course, more sophisticated approaches would be to consider job qualifications or wages (Basso et al. 2020: 140), as in reality not every job is equally attractive to every individual.

Number of Jobs	Attractivity value	Description / Attractivity	Count
0	0	Not attractive	2,752
1-20	1	Not very attractive	1,330
21-100	2	Medium attractivity	1,070
101-250	3	Very attractive	538
251-1000	4	Highly attractive	710
1001-8649	5	top	231

Table 1: Weighting attractivity of job destination points (own elaboration).

The number of jobholders (employers and employees) in the raster cells for Vienna vary from 0 to 8649 (Statistik Austria, 2014). Prior to the computation of travel times, all cells with the value 0 were excluded from the layer, as in terms of job accessibility they are not attractive to be reached. Table 1

[2] national statistical classification of economic activities based on the NACE classification of the European Union (Statistik Austria, 2008)

demonstrates how destination points were weighted with a scale from 0 to 5 according to their attractivity or number of jobs. Figure 12 shows the distribution of jobs according to this classification.

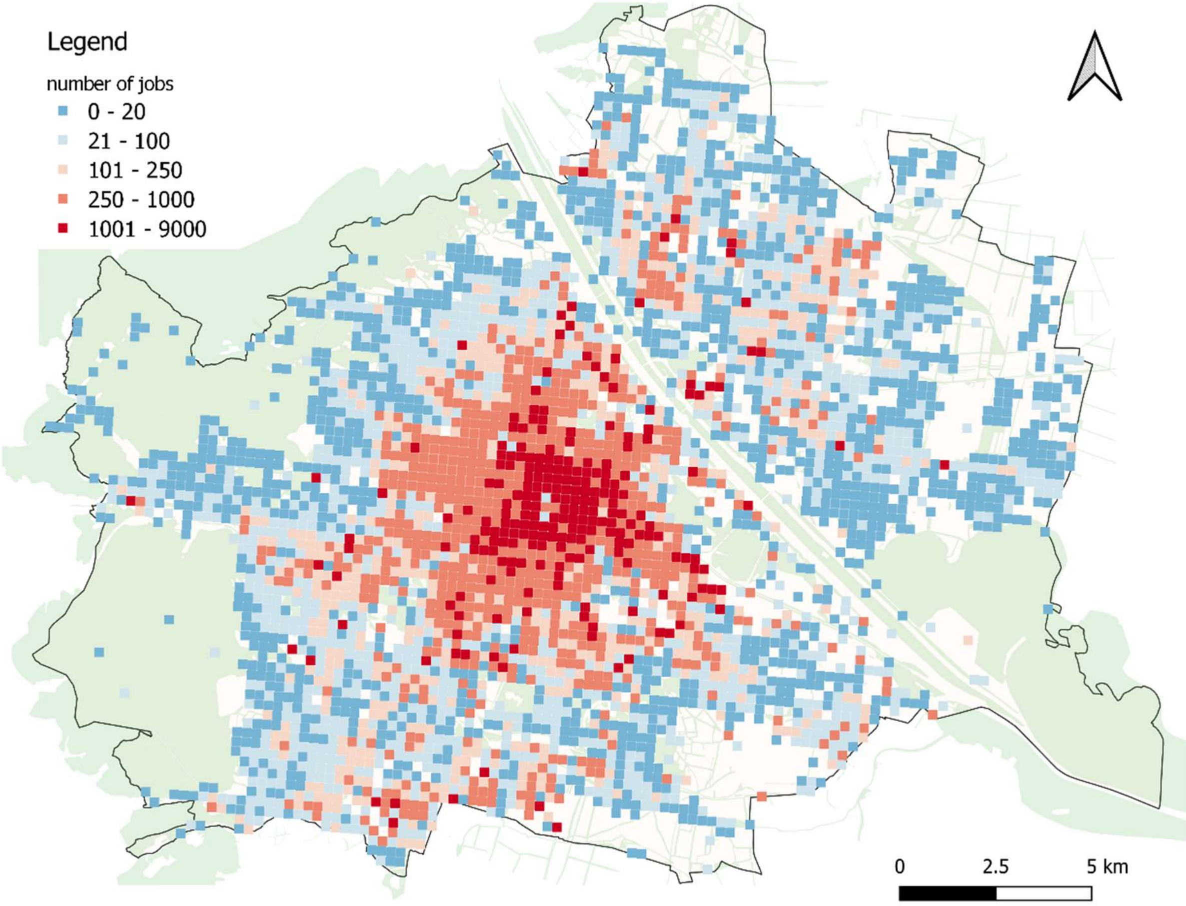

Figure 12: distribution of jobs in Vienna. (Own figure based on City of Vienna, 2021; Statistik Austria, 2014)

<u>Center Accessibility</u>

Centers and central areas were chosen according to the technical concept "*Centers of urban life. Polycentric Vienna*" (see chapter 3.2.3), based on the Urban Development Plan 2025. Centers were chosen in order to enrich the analysis and understanding of accessibility. According to the understanding of the concept and subsequently also this thesis, centers account for a great variety of functions and usages, such as retail and commerce, culture, social infrastructure, and public space (MA18, 2020: 11). Centers are thus understood to be places were various kinds of opportunities bundle and which play an important role for participation in society.

Same as for jobs, an assessment of the attractivity must be executed. In the centers technical concept, 49 centers are defined in different rank categories to enhance the polycentric development of the city. Those ranks will be translated into the GIS accessibility model through a categorization from "not attractive" to "very attractive" to reach (numeric rank values 1-4).

Table 2 describes the classifications of centers according to their type and attractivity.

Type of Centre	**Attractivity value**	**Description / Attractivity**	**count**
Metropolitan Centers	**4**	Supra-regional importance: Relevant not only for the city itself, but for the whole city region and even on an international scale. They are characterized by a very diverse and specialized offer of top-ranked goods and services.	2
Main centers	**3**	Regional importance: They mainly attract people from neighboring areas and provide a high variety of services and goods.	20
District centers	**2**	District centers are of importance for the whole district they are located in. They are mostly located in the outer districts, where they fulfill certain functions of higher-ranked centers which are by trend located close to the first district.	18
Local Centers	**1**	Local centers cover daily needs, but do not attract people from far-away neighborhoods.	8

Table 2: Weighting attractivity of centers and central areas (own elaboration based on MA18, 2019: 31)

Figure 13 displays the centers considered in the analysis. As the computation of travel times demands to be expressed as points, central areas had to been simplified to one point. The location of those points was selected considering where density of retail and services was highest, as well as from the author's personal experience.

Figure 13: Centers and Central Areas in Vienna according to the "Polycentric Development concept". (Own Figure based on City of Vienna, 2021; MA18, 2020a).

At this point it is necessary to outline an important emerging bias: As outlined in chapter 2.2.2 transportation system and land use are two crucial factors for accessibility. On the other hand, the better accessible a place is from various origins, the more likely it is to be attractive for a concentration of activities. Figure 14 (El-Geneidy & Levinson, 2006: 2206) below explains the relations between the different components that have influence on each other.

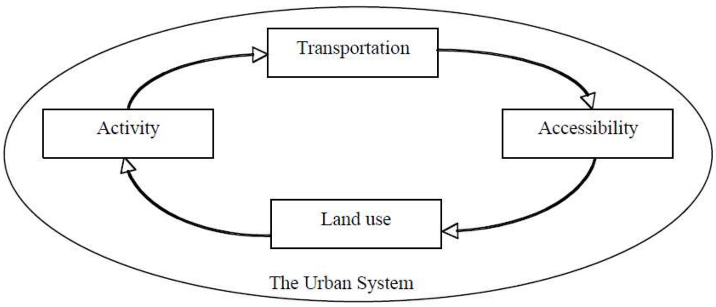

Figure 14: Interplay of the transport and land use system. (El-Geneidy & Levinson, 2006).

Nevertheless, the decision to analyze accessibility to central areas was kept, because the variety of metropolitan, main, district and local centers included ensures that also case study areas located farther away from the central district of Vienna, could account for a relatively high accessibility to different centers.

4.2.3. Calculating Travel Times – Motorized Transport and Bike

After defining both origins and destinations and creating the respective layers, the next step is the **calculation of travel times**. For job accessibility the origin-destination-travel-time matrices have an extent of 23 (origins) x 6631 (destinations) = 152,513 travel routes and times that have to be computed for each mode. For centers accessibility the output will be 23 (origins) x 49 (destinations) = 1,127 rows origin-destination-travel-time matrices, so computation times are significantly shorter.

Table 3 shows the structure of the origin-destinations-matrices. Travel time always refers to the **fastest route** considering certain preferences and rules for every mode.

Origin ID	**Destination ID**	**Travel time (h)**
11	8	0.5924

Table 3: Example for the Structure of the origin-destination-matrices (own elaboration).

Accessibility by motorized individual transport and by bicycle has been calculated with ***Open Route Service*** provided by the *Heidelberg Institute of Technology* that closely cooperates with the *GISScience Research Group* at Heidelberg University[3]. *Open Route Service* is an open-source plug-in for QGIS. The functions included in the model work with a transport network model in the background, which is based on Open Street Map data. A complete documentation of all parameters is available on *github*, a platform for exchange of mostly open-source projects. According to the documentation (Heidelberg Institute of Technology, 2021), the travel time calculation considers type of street, cycling or pedestrian infrastructure, street surface, steepness, as well as a variety of rules for transport participants' behavior (e.g., turning, access restrictions, etc.). It is a quite sophisticated model with a lot of effort in the background and thus seems perfectly suitable for the purpose of this research. The functionality used for this thesis was **Matrix from Layers.** The matrix algorithm returns duration and distance for multiple origin and destination points. Figure 15 is a screenshot of the mask for setting parameters for the matrix calculation. Origins and destinations layer have to be included and the travel must be chosen. There are different modes available for cycling. "*Cycling regular*" which uses a default set of speeds and road type preferences and "*Cycling road*" which gives preference to asphalted or paved

[3] *GISScience Research Group* at Heidelberg University: GIScience / Geoinformatics Research Group Heidelberg (GIS) (uni-heidelberg.de)

routes (higher speed) and allows the usage of secondary and tertiary roads, even if no cycling infrastructure is provided[4]. For this thesis the option "*Cycling road*" was chosen, as it produced almost no missing values in contrary to "*cycling regular*".

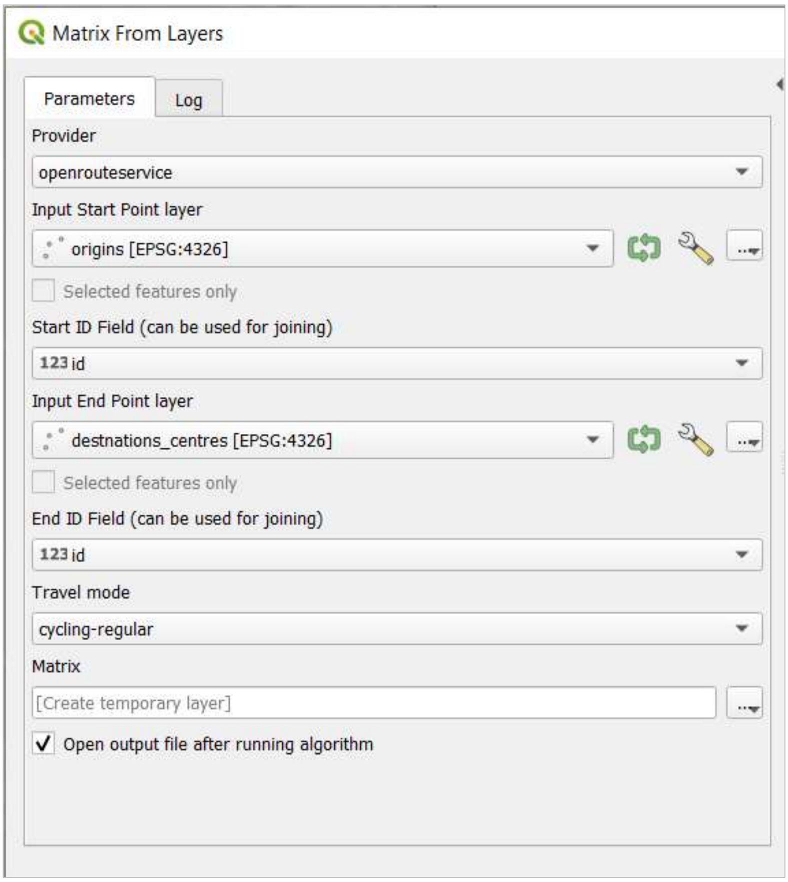

Figure 15: ORS settings for calculating travel-time-matrices. (Screenshot of ORS plug-in; Heidelberg Institute for Geoinformation Technology, 2021.)

4.2.4. Calculating Travel Times – Public Transport

For the calculation of travel times by public transport, there is no cost-free tool available that allows to compute big Origin-Destination-Matrices as needed in the case of this research. Therefore, it was necessary to set up an **own network model for public transport** and walking, making use of the functions provided in **ArcGIS Pro**. This step consumed a considerable amount of the total time invested for the empirical part of the research. The following paragraphs will sum up which steps were undertaken, and which parameters have been defined. The parameters influence the outcomes of travel times computations and eventually of accessibility levels.

[4] Java Code for „Cycling road" used for this thesis: openrouteservice/RoadBikeFlagEncoder.java at master · GIScience/openrouteservice · GitHub

Input data for the model

Accessibility for public transport has been especially challenging to compute until recently. With the introduction of the **General Transit Feed Specification (GTFS)** data format in 2009, the basis for fully displaying public transit networks, including departure times and routes, was created. GTFS data consists of a necessary **minimum of six text files** (.txt), but up to fourteen text files offering additional information can be provided. The files work as a relational data structure, where different objects relate to each other by unequivocal identification (Gidam et al., 2020: 318), allowing the creation of a topological model (georeferenced information is not necessary for calculations). In Austria, data in GTFS format are provided by the *Wiener Linien*, the Viennese public transport operator (Wiener Linien Gmbh & Co KG, 2017) and by the *ÖBB*, the biggest Austrian Railway company (ÖBB-Personenverkehr AG, 2018). Table 4 shows the required data sets that must be included in the GTFS-format (Gidam et al., 2020: 319):

Text file name	Content
Agency.txt	Information on the operator of the public transport system
Stops.txt	Public transport stops (ID and names)
Routes.txt	Information on public transport lines (ID, names, type)
Trips.txt	Different trips and services for all routes (including start- and endpoint)
Stop_times.txt	All scheduled arrival and departure times for each station and routes
Calender.txt	Defines regularly-occurring scheduled transit services
Calender_dates.txt	Exceptions from the scheduled services.

Table 4: Necessary components of a GTFS dataset (own elaboration).

The GTFS data from *Wiener Linien* and *ÖBB* had to be merged in the forehand of the built-up of the model. An R Script was written for this purpose. Finally, the merged GTFS data included eight text files, including the mentioned above and the file “transfers”, which offers information on transfer times between connections, although only for the *ÖBB* data.

The second input data set needed are the street lines. For this model, the **GIP-Dataset** (*Graph Integration Platform)* for Austria was used. GIP is an integration project, implemented by the Austrian public administration, that offers high-quality transport data for public transport, cycling, walking and car transport and is available as Open Government Data (OGD). It offers the most detailed street center lines as shapefile, as well as detailed information on admitted uses for each segment of the street (ÖVDAT, n.y.).

<u>Preparation of the input data for the model</u>

After loading both input datasets into a new ArcGIS Pro project, the tool **GTFS to Network Dataset Transit Sources** was applied. This is a conversion tool offered by ArcGIS Pro. The result includes the public transport stops and the connections between them, offering a topological model of the public transport network. Figure 16 shows the first results for the GTFS data provided by *Wiener Linien* and *ÖBB (*reduced to Vienna beforehand).

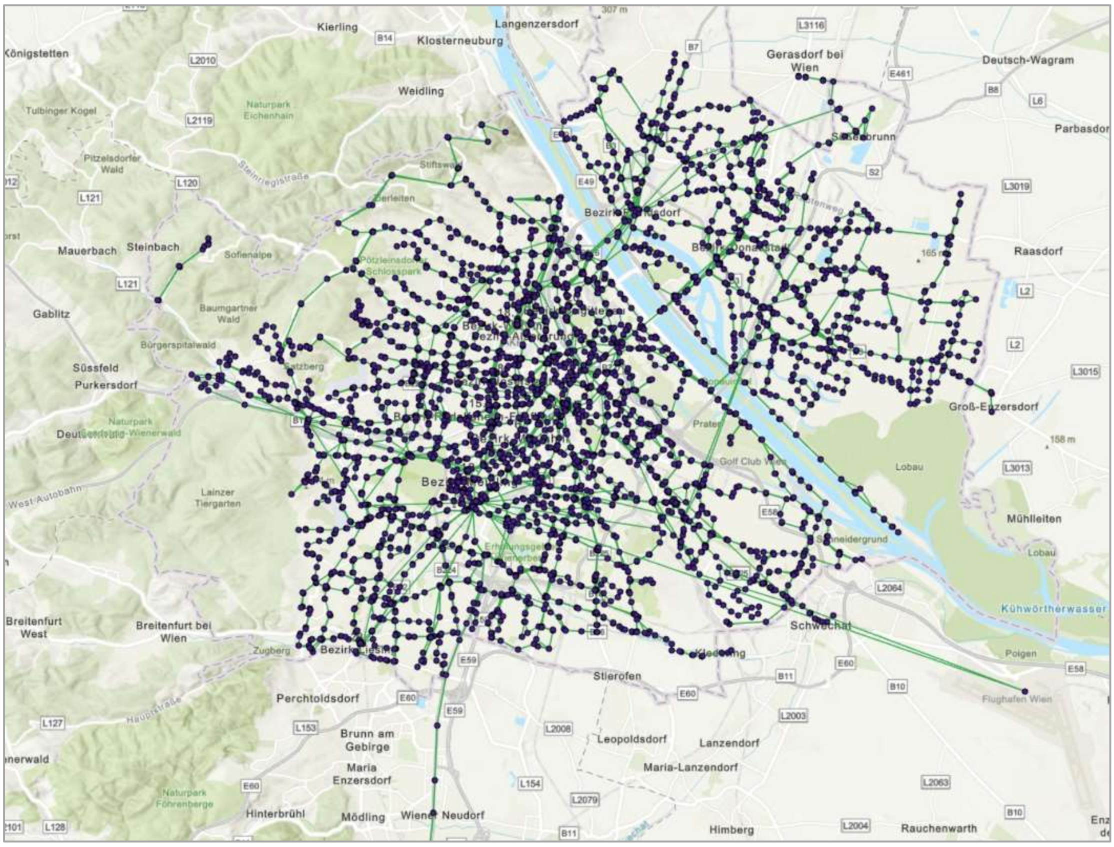

Figure 16: Topological Model of the Viennese Public Transport Network. (Own Figure based on City o Vienna, 2021; ÖBB-Personenverkehr AG; 2018 Wiener Linien ,2017).

The next step was to **restrict pedestrian access for certain street types.** This information is given as binary-coded decimal in the GIP dataset. Based on this, a list with allowed street sections for pedestrians (excluding highways, railway tracks, etc.) was created and the following code was used to define pedestrian access and restrictions:

Code Block
```
allowed = list((1,3,9,11,1025,1027,1033,1035,2097153,2098179,2098185,2098187,2383629,2383631,3964687))

def Reclass(ACCESS_TOW):
    if (ACCESS_TOW in allowed):
        return "N"
    else:
        return "Y"
```

Figure 17: Formulating Restrictions for Pedestrian Access (Screenshot of ArcGIS Pro Software).

Next, the street network lines have to be connected to the previously loaded public transport model. The function **Connect Network Dataset Transit Sources to Streets** is used to create a second stop on the street graph, by creating the shortest possible connection between the real location of the stop and the street graph line (see Figure 18).

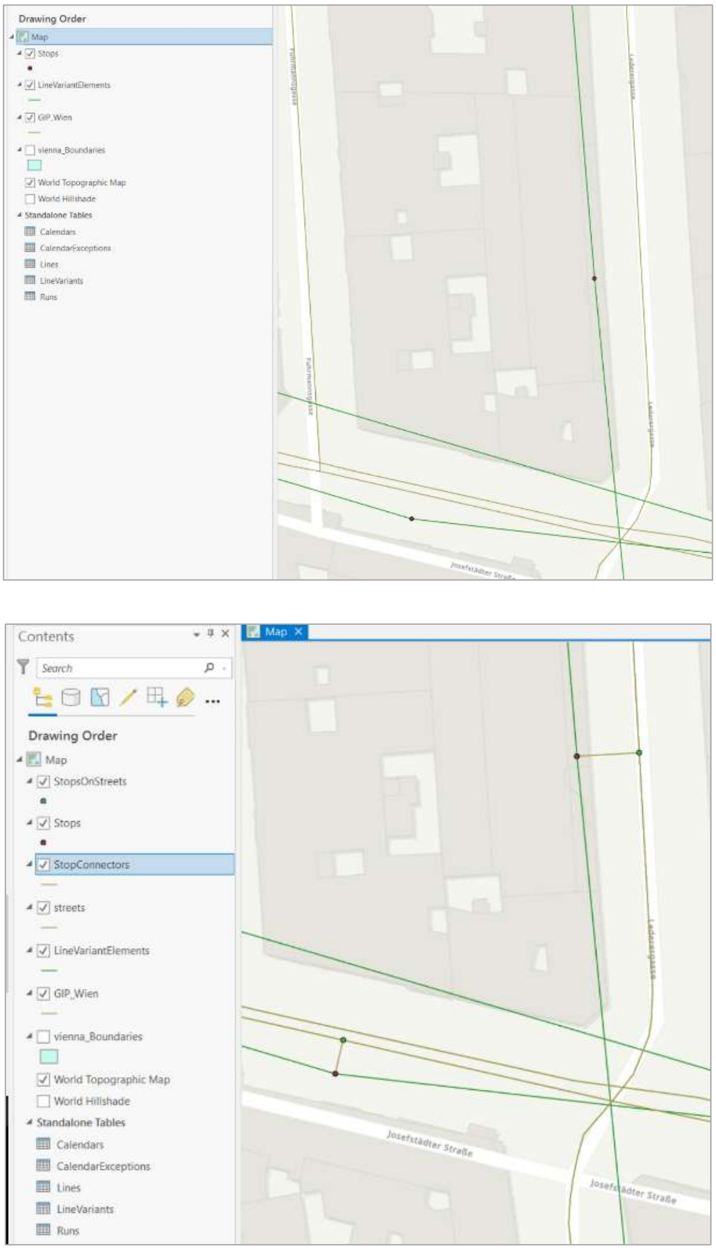

Figure 18: Creating stops on the street layer and connecter lines in order to connect networks (Screenshot of ArcGIS Pro Software).

Creating the network dataset

In order to create the network, the following five feature layers are needed: *Streets, Stops, StopsOnStreets* and *StopConnectors* (both created through previous step) and *LineVariantElements* (see Figure 19). The network dataset allows to record connectivity rules between the different features and to define crossovers between the different layers, e.g., how much time it takes to overcome the distance from the street to the mean of transport for the case of pedestrians. The function **Create Network Dataset** is used to create the network. It also includes the information from the GTFS data.

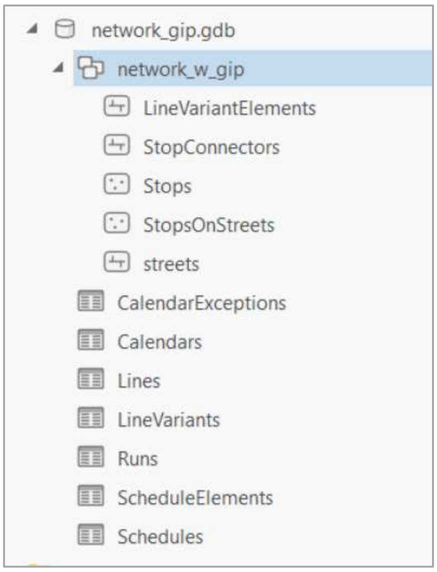

Figure 19: Layers for Network creation (Screenshot of ArcGIS Pro Software).

<u>Defining network connectivity</u>

After creating the network dataset, the first step is to define group connectivity between the five mentioned feature layers. This way, the basic rules for connecting the network elements have been defined and trips can be calculated including public transport and walking. Figure 20 is a screenshot of the group connectivity defined for the Vienna public transport network. Three groups have been defined, with each group containing both edges and junctions. The first connectivity group includes the streets layer (edge) and the Stops on Streets (junctions). The second includes *StopConnectors* (the lines between streets and public transport stops*), Stops* and *StopsOnStreets*. The latter connects group 1 to group 2. The last group encompasses *LineVariantElements* (the topological connection between public transport stops) and *Stops*.

Moreover, the connectivity policies for edge sources can be defined. Endpoint connectivity is used in this case, meaning that line features are only considered connected in their network if their endpoints are coincident. For the stops junction the connectivity policy is **Honor,** meaning that transit stops obey the connectivity policy of the edge source of which they are connected. In the case of StopsOnStreets the connectivity policy Override is chosen, meaning that it will not honor the endpoint rule of the edge source, and thus also connects to the streets on other than endpoints.

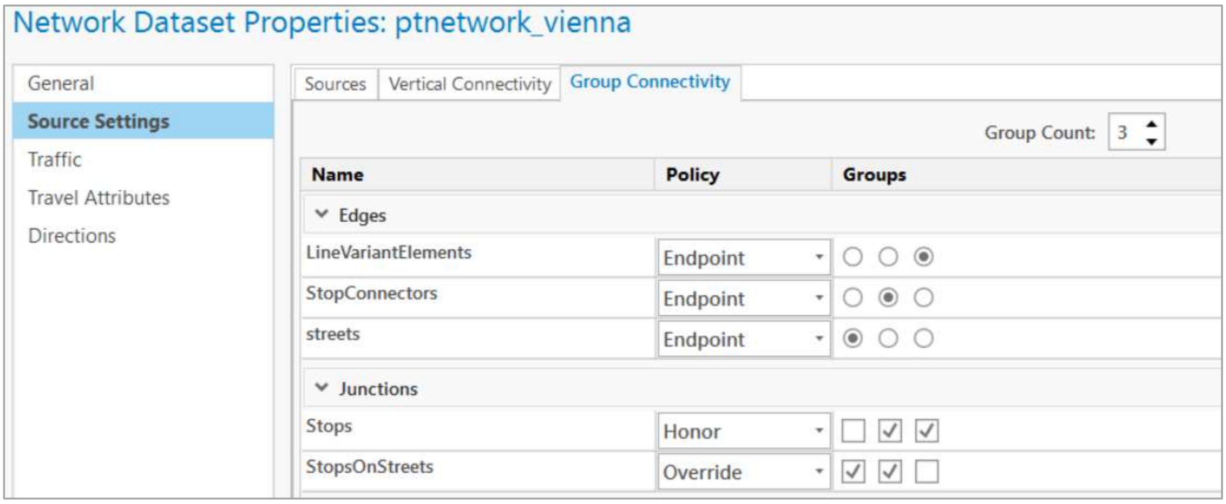

Figure 20: Setting up connectivity of the Network (Screenshot of ArcGIS Pro Software).

Defining travel time as cost attribute

Secondly, the **cost attribute travel time** must be defined in order to allow the later calculation of travel times (see Figure 21). Evaluation types can be defined for each of the edges and junctions of the network. For the LineVariantElements, which represent the public transport lines, the evaluator type "public transport" is used, which retrieves data from the GTFS text files. For the Stop Connectors a value of 1.5 minutes was chosen, assuming that it takes one and a half minutes on average to board a public transport vehicle. For the streets, a walk speed of 70 meters per minute, or 4.2km/h was assumed. Other cost attributes, such as length of distance travelled, could be defined similarly to the travel time. However, they are not needed for the purpose of this research.

The travel times could be modelled much more precisely, if barriers, such as crossings, bridges, underground passages or slopes, would be considered.

Including Pedestrian Access Restriction

New restrictions can be added to the model. In this case the pedestrian access allowance, which was defined in a previous step, is included to the model using the expression !RESTR_PED! == "Y".

Finally, after completion of all this steps, the network can be built using the function **Build Network.**

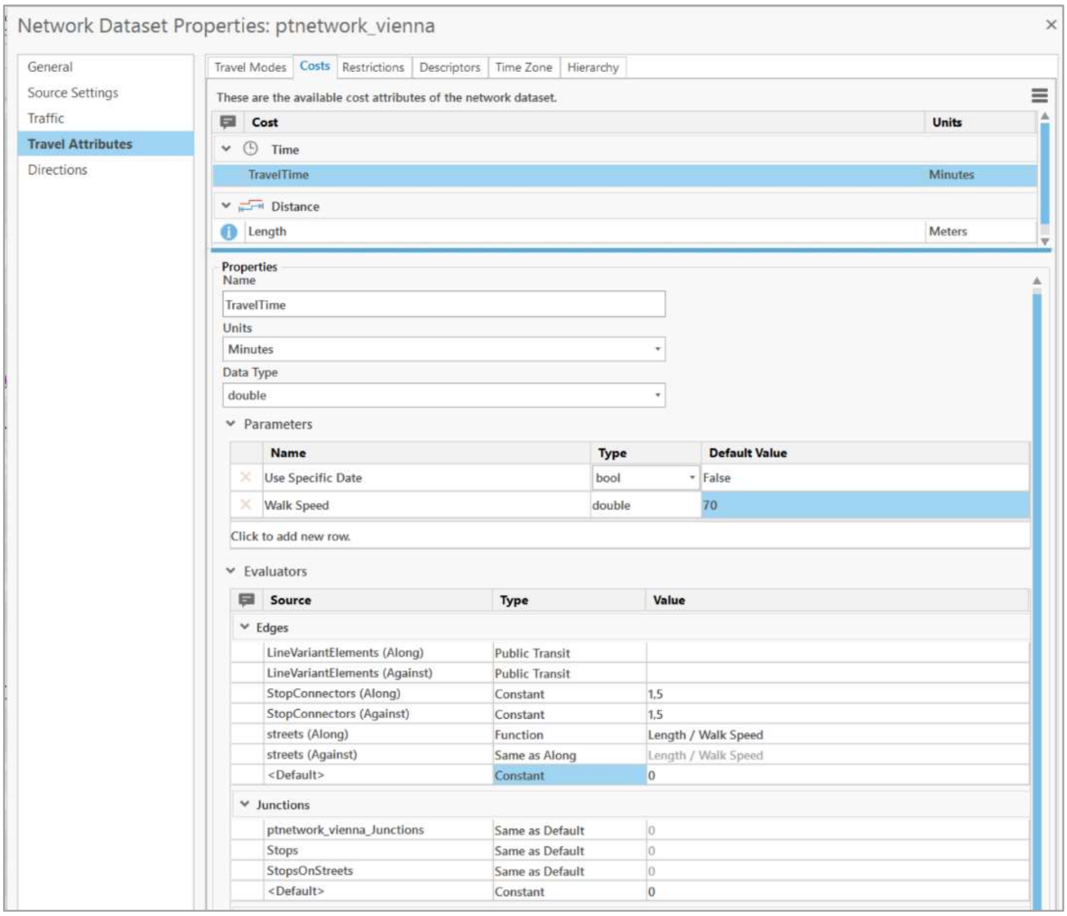

Figure 21: Defining travel time as cost attribute (Screenshot of ArcGIS Pro Software).

<u>Creating the Origin-Destination-Cost Matrix Analysis Layer</u>

ArcGIS Pro provides a function to calculate Origin-Destination-Cost matrices. This is needed for calculating travel times from the origin locations to destinations. The origins and destinations layer have to be imported into the matrix analysis layer first. Then, the cost attribute to be calculated, in this case travel time, must be set. Moreover, the weekday and exact starting time can be set.

For public transport, it is important to reflect the quality-of-service provision in the results. Different to travel by bike or car, public transport is fixed to certain schedules and operating hours. Thus, the travel time calculation process must be iterated over a period of the day, with intervals of several minutes. Ideally, also differences between weekdays and weekends, as well as night and day are included (Fransen et al. 2015: 182). Thus, the following starting times were set for the iteration of the analysis:

1. Monday, 07:30 to 08:30 with 5 minutes interval to capture peak travel time
2. Thursday, 11:00 and 11:15 to capture for non-peak
3. Thursday, 02:00, 02:10, 02:20 to capture night transport
4. Sunday, 06:45, 06:55, 07:00 to capture Sunday schedules

After running the Origin-Destination-Cost matrix operation for the chosen time intervals, the travel time can be found as attribute in the OD cost matrix.

4.3. Evaluating Accessibility

The next step is to evaluate accessibility based on the calculated travel times and the assessment of destinations. Travel times will be valued as impedance, following the gravity-based measure of accessibility. This attempts to model traveler's perception, that closer opportunities are more desirable to reach than those located farther away (Foth et al., 2013: 4). As big amounts of data had to be processed in this step, a script in R was prepared to manipulate and analyze data, which also facilitates later changes to the calculations of accessibility. The following paragraphs shortly sum up the calculation process that has been done in order to generate accessibility indices that will be discussed in the empirical findings.

4.3.1. Calculating one index for each mode and area

After calculating the travel times between origins and destinations for different modes, there are several steps to be effectuated for calculating accessibility.

Preparing the OD cost matrices for analysis

Firstly, the OD cost matrices for bike, car and public transport have to be imported. The GIS allow to save it in .csv format. For the car and bike travel times, that were calculated with the ORS tool, calculations had to be made in several runs, as the maximum API-calculation allowance was exceeded for computing travel times between the 22 origin points and almost 4,000 destination points. As a total of 3,879 job destination points is to be reached, the matrices are quite extensive, including 19,395 rows. The first step was thus joining the split-up matrices.

For public transport, the matrices could be calculated in one run. However, as mentioned previously the process was iterated several times. Thus, numerous matrices for the different starting times had to be summed up by calculating the mean. Eventually, with one matrix for each destination type (jobs and centers) and mode (car, bike, public transport) available, the evaluation of accessibility can be started (15 matrices: three for each of the four study areas, plus one for each control point respectively). Moreover, as described in chapter 4.2.1, five starting points were chosen for each area beforehand. The idea was to include different walking distances that have to be overcome within the area. Thus, in the current step the mean travel time for each area to each destination has to be calculated by forming the mean value of those five respective travel times. To tackle the attractivity of the points to be reached into consideration, the prior described **assessment of destination's attractivity**, according to 4.2.2, is joined to the matrices, based on the destination connecting field.

Including Impedance (Travel Time)

As a next step, impedance, the cost of overcoming distance in space, has to be introduced to the calculation model. To do so, the previous assessment for all destinations (from “very attractive” to “not attractive”), will be altered in the way that **greater travel time between origin and destinations will mean less attractivity**, following the assumption that greater distance and travel time makes it less attractive for people to travel to certain areas (including travel cost in the model). The graduation will be mode-specific (e.g., travel times must be evaluated differently for cycling and motorized transport).

Inclusion of travel times can either be done through different functions or predefined travel intervals. In this case several predefined travel intervals where chosen, such as Fransen et al. (2015: 182) described in their study. This represents a mixed model (Bunel & Tovar, 2014: 1326), where time-travel areas defined where all job-destinations within the area receive the same impedance value. Expressed in a function, the decay function is rectangular (Levinson & Wu, 2020: 137). Bunel and Tovar (2014: 1326f) argue that the mixed model allows a better fitting with actual transportation patterns than decay functions, as this may over-weight distant jobs and under-weight closer ones. Although other authors argue that other functions, such as the frequently used negative exponential function (Levinson & Wu, 2020: 137) might be slightly more accurate, the decision to work with several breaking points for impedance evaluation was taken, as it is far easier to apply. Moreover, according to the study on different accessibility measurements by Bunel & Tovar (2014: 2334), using a decay-based specification or a concentric rings approach does not lead to significantly different results among time-based models.

Table 5 represents the maximum, minimum and mean travel time for each mode, deduced from all travel times calculated. Moreover, the predefined travel intervals as well as their assessment is included in the overview. The intervals differ between modes, as distances in terms of travel times are perceived differently for different modes.

Car	Bike	Public Transport
Max: 59.6 min **Min: 0.07 min** **Mean: 22 min** **Very Good (1): Below 10 min** **Good (0.8): 10-20min** **Medium (0.6): 20-30min** **Bad (0.4): 30-40 min** **Not interesting (0.1): >40min**	**Max: 106.6 min** **Min: 0.06 min** **Mean: 30 min** Very Good (**1**): below 10min Good (**0.8**): 10-20 min Medium (**0.6**): 20-30min Bad (**0.4**): 30-45min Not interesting (**0.1**): >45min	**Max: 182.95 min** **Min: 0.25 min** **Mean: 50 min** Very Good (**1**): below 15min Good (**0.8**): 15-30 min Medium (**0.6**): 30-45 min Bad (**0.4**): 45-60 min Not interesting (**0.1**): >60 min

Table 5: Impedance used to include travel time in the model (own elaboration).

Calculating the accessibility indicator

The impedance value attributed between 0.1 and 1 is a factor with which the attractivity of a destination is multiplied. The attributed values to attractivity of jobs and central areas have been outlined in chapter 4.2.2. Given an example, if a job destination with an initial evaluation of 3 (very attractive) can be reached by public transport in between 15 and 30 minutes, the following equation will apply: **accessibility = destination attractivity x travel cost (=time)**

Contribution to accessibility index = 3 (destination attractivity) x 0.8 (impedance rested) = 2.4

Thus, in the final evaluation of accessibility, this connection will not count for the value of 3 but will be reduced to 2.4. The final accessibility index for each origin-destination-matrix will be the sum of this operation's result for all connections calculated. However, the number per se does not really enable to directly draw some conclusions. The accessibility indices for the areas and modes must thus be compared amongst each other to derive any results concerning distribution of transport benefits.

4.3.2. Comparing accessibility indices

After having calculated accessibility indices from every case study area and the three control points to both jobs and centers, the results must be made comparable in order to deduce first conclusions for distributional questions. However, as previously mentioned, it is not the goal to state whether the transport system is fair or not. It will rather give a first insight into possible inequalities and allow to derive some general recommendations for urban and transport planning.

This is possible, as the results of gravity-based measures can be compared to identify underserved areas in a city, especially when it comes to comparing different mods (El-Geneidy & Levinson, 2006: 7f). The assessment of accessibility levels is, however, a challenging process (Pyrialakou et al., 2016: 256) and values are not meaningful standing alone, but only in comparison (Cheng & Bertolini, 2013: 102). Thus, the best way to work with the results is by looking at **relative accessibility** across a region (El-Geneidy & Levinson, 2006: 9f). El-Geneidy & Levinson (2006: 9f) suggest normalizing data to a range between 0 and 1 in order to make accessibility levels for each mode comparable amongst each other. Martens et al. (2021: 688) suggest departing from the maximal level of access experienced in the analyzed region and see how big the gap to the other areas is. They propose to define a maximum gap that is compatible with goals of equity and transport justice.

The outcomes have to be inspected both by considering differences between the areas (<u>space-related equity</u>), as well as between different modes for the same area (<u>mode-related equity</u>, e.g., is the level of accessibility by motorized individual transport significantly higher than by public transport?), as proposed by Martens et al. (2012: 689). Moreover, an attempt to compare accessibility indicators across both areas and modes is undertaken. This will allow to check, whether an area's bad performance in accessibility levels with one transport mode could potentially weighted up by the good performance of another one, or if overall accessibility of an area can be said to be deficient.

5. Empirical Findings

The empirical findings from the previously described calculation of accessibility levels will be presented in this chapter. Both accessibility to jobs and to centers from the four case study areas will be discussed. The goal is to provide an answer to the first research question: **In how far does accessibility differ between modes and areas in the analyzed cases?**

As described in the previous chapter, the accessibility of each case study area for different modes is expressed by an **index**. The **numeric value of the index itself cannot be interpreted standing alone**. It is rather necessary to **set it in relation with index values in other areas.** Comparing accessibility indices in a relative manner allows to deduce relevant differences in accessibility between the areas and should thus be preferred over comparing numbers directly (El-Geneidy & Levinson, 2006: 17; Golub & Martens, 2014: 14ff). Moreover, it must be acknowledged that using indices can hold multiple risks, since they evoke the impression to be universal and objective. However, they are always influenced by multiple parameters settled in the methodology of data collection and calculation processes. Moreover, the researcher's cultural and social background, as well as prejudices will possibly manifest in the supposedly objective system. Nevertheless, high efforts have been undertaken to make the calculation of the accessibility indexes used for interpretation of findings traceable und understandable (see chapter 4).

In order to not derive wrong hypotheses or assumptions, all results are to be examined with caution and considering that the computations are based on network models that try to represent real conditions of the transport network in the best feasible way. All parameters influencing the results have been thoroughly documented in chapter 4.2. However, the model will never be able to fully reflect the variety of conditions having influence on accessibility. Moreover, Bunel and Tover (2014: 1323) have pointed out that different measures (some of them presented in chapter 2.3.1) lead to discrepancies in results. Thus, the interpretation of results ought to be understood as an approach to understand the distribution of accessibility across Vienna, rather than as an absolute value.

5.1. Job Accessibility from the analyzed areas

Job accessibility is, as mentioned in previous chapters, one of the most frequently used indicators for evaluation of accessibility levels. Consequently, it is used in several case studies as mean to explore distributional inequalities within urban transport systems (Boisjoly et al. 2017; El-Geneidy & Levinson, 2006; Wang & Chen, 2015).

In the case of this research, information on the number of jobs was only available for the year 2011, when the last extended census was conducted (Statistik Austria, 2021). New data on this behalf is to be published in October of 2021, which will be after the foreseen completion of this work. Data on the number of jobs was available for the centroids of a 250 meters per 250 meters raster for the whole city of Vienna. However, no details on economic classification of the jobs, on remuneration, nor on other qualitative information could be derived from the accessible data. Details on the dataset are described in chapter 4.2.2. Although the data dates back to 2011, it allows to get a general notion of major job locations and of job accessibility levels.

Throughout the calculation of the indicators for job accessibility the main conditioning factors for the results are *a)* the categorization of job raster centroids according to their attractivity (from very attractive to reach to not attractive, see chapter 4.2.2) and *b)* the impedance, expressed in travel time (see chapter 4.3). Based on these figures, indices have been calculated making use of an R script. The accessibility index (**A_i**) can be understood as the sum of the products from job attractivity, and the impedance based on the travel time from the given case study area:

$$Ai = \sum_j D_j \ f(C_{ij})$$

A_i= Accessibility at Origin i
D_j = Destination (Job location) j weighted by attractivity (Number of jobs)
f(Cij) = Mode-specific Impedance function
Cij = Travel time from Origin i to Destination j

Calculated according to the methodology described chapter 4.3.1, the accessibility indices in Table 6 below, present one mean indicator for each area (five origin points per area) and starting times in the respective study areas. The results are presented not only for the four chosen case study areas, but as well for the comparison areas *Karlsplatz* and *Volkstheater* in the inner city. This will allow to effectuate the comparison between the most accessible communities within the city and those analyzed, as proposed in literature by Martens et al. (2012: 687).

	ID	area_name	Car	bike	public transport
Case Study Areas	**1**	Simmering	6,460.9	5,242.5	4,235.3
	2	Atzgersdorf	5,693.9	4,039.2	2,833.4
	3	Josef-Bohmann-Hof	5,708.5	4,276.9	3,727.6
	4	Friedrich-Engels-Platz	6,660.8	5,576	3,907.9
Comparison Areas	**5**	Karlsplatz	7,174.7	6,274.1	5,730.4
	6	Volkstheater	7,225.2	6,284.3	5,718.8

Table 6: Calculated Job Accessibility Indices – absolute index values. (own elaboration).

The analysis has included a high number of destination points, and since the sum over their product with impedance was calculated, the resulting index numbers are relatively high. As proposed by several authors (Foth et al. 2013; Levinson & WU, 2019: 131; Martens et al. 2012: 689f) a closer look will be taken at the **comparison of the indices**, reflecting upon the **relative differences between the case study areas' accessibility levels**. Precisely, this will be done by firstly comparing the accessibility to jobs between the analyzed case study areas and the comparison areas (*Karlsplatz* and *Volkstheater*), while considering different modes (space-related equity). Secondly by comparing between the three analyzed modes of transport within each case study area (mode-related equity). Finally, a comparison across both transport modes and areas will allow to get a better notion of differences in overall accessibility.

5.1.1. Comparison between neighborhoods

In order to tackle space-related equity, a closer look at the distribution of accessibility levels between areas ist taken. Figure 22 displays job accessibility levels in the respective areas as percentage share of the maximum value for each transport modes. In this case job accessibility levels are highest for all transport modes in the comparison area *Volkstheater* (see Table 6). Thus, the other areas' index values have been compared with those of *Volkstheater*, as the ambition is to detect differences between the best-off and the case study areas. For example, Figure 22 evidences that job accessibility by public transit from (2) *Atzgersdorf*, only reaches 49,4% of that of *Volkstheater* and that it the gap is of 50.6% in the comparison.

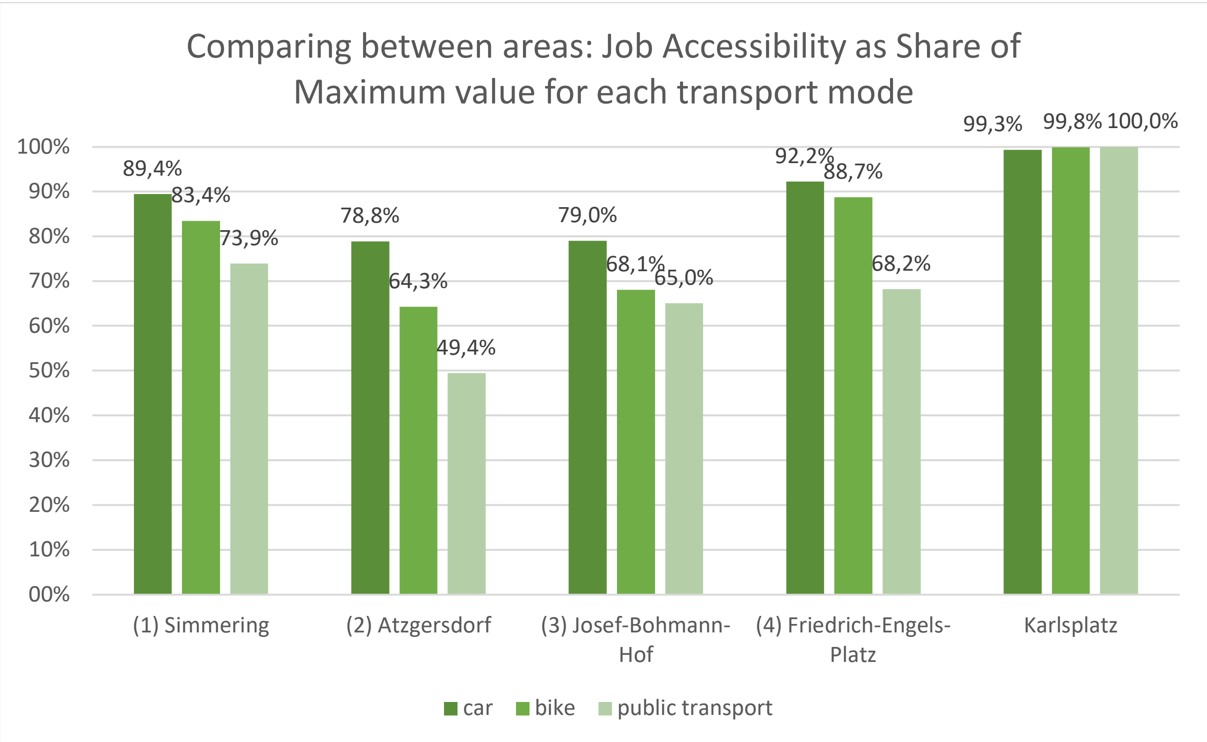

Figure 22: Comparing Job Accessibility between neighborhoods. Share of index value reached by best-off area. (Own Figure).

The first striking evidence from these results is **that differences in job accessibility by bike or public transport are considerably higher than for motorized individual traffic** (car). Looking at **job accessibility by car**, only small gaps in the accessibility levels can be identified for case study areas 1 and 4. On the one hand these two areas are the closest in terms of geographical proximity to the central city. On the other hand, they may profit from jobs locations located nearby. For case study areas 2 and 3 car accessibility is about 21% worse than in the area with best accessibility, but it is still a narrow gap when compared to other transport modes.

For **job accessibility by bike**, the comparison between the analyzed cases and the additional comparison points shows similar tendencies to that of accessibility by car. Overall, the differences between the areas seem to be higher than for car accessibility, which could intuitively be explained by the fact that shorter distances can be effectuated within similar time (of course depending on the quality of infrastructure and traffic situation) and the impedance function has been modelled accordingly (see chapter 4.3.1). Case study area 4, *Friedrich-Engels-Platz,* shows the best jobs accessibility index among the analyzed cases, reaching 88.7% of *Volkstheater's* index value. This might be explained due to proximity of job locations. Case study areas 2 and 3 evidence lower levels of job accessibility by bike, their gap to the best-off area being 64.3% and 68.1% respectively. A closer look should thus be taken at the availability of jobs in cycling distance and at the cycling conditions, such as slopes or type of cycling infrastructure, that could have had influence on results.

Finally, it is remarkable that **job accessibility by public transit** is reaches significantly difference index levels in the analyzed areas. Case study area 2, *Atzgersdorf,* stands out with bad performance, evidencing a job accessibility level only half as high as in the central city comparison area *Volkstheater.* In case of study area 3, *Josef-Bohmann-Hof*, on the other hand job accessibility by public transport reaches a similar performance as cycling. Nevertheless, public transport only reaches 65% of *Volkstheater's* accessibility levels. An important finding is the fact that although case study area 4 performs excellently compared to the others in the modes car and cycling, it has poor performance in public transport, albeit being the most centrally located area in terms of distance to the city center. In case study area 1, *Simmering*, job accessibility by public transport is significantly better than in the resting case study areas, although still being 26% lower than in *Volkstheater*. This is probably related to the immediate proximity to high-ranked means of public transport, including subway and suburban commuter train.

Summing up the intra-neighborhood comparison, aiming at identifying space-related inequalities in the distribution of transport benefits, showed that case study area 2, *Atzgersdorf*, in the Southeast of the city evidences the lowest overall job accessibility levels. However, job accessibility by car is similar to case study area 3. Case study area 3, *Josef-Bohmann-Platz*, which is located North of the city center and the Danube River, accounts for the second worst results in the undertaken comparison. This fact will be analyzed more thoroughly in the following chapter. Case study area 4, *Friedrich-Engels-Platz*, performs best out of the analyzed areas in jobs accessibility by car and bike, but shows a relevant gap when it comes to public transit, whereas case study area 3, *Simmering,* evidences the smallest gap to the best-off area.

5.1.2. Comparison between modes of transport

Additionally to comparing accessibility levels between neighborhoods, Martens et al. (2012: 689) propose looking at mode-related inequalities within each area. Table 7 below displays differences in job accessibility by different modes. The highest accessibility index of each area, in all cases being reached by car, constitutes 100% and **job accessibility by the other modes is expressed as percentage of the maximum value**. A remark that must be made when comparing modes, is that albeit average driving speeds (and not the maximum allowed speed) are taken as parameters for calculation of car and bike accessibility (Heidelberg Institute of Geoinformation Technology, 2021), the model is likely to create better results for car, as for example time needed for accessing the car or finding a parking lot cannot be considered.

			job accessibility		
	ID	area_name	car	bike	public transport
Case Study Areas	1	Simmering	100.0%	81.1%	65.6%
	2	Atzgersdorf	100.0%	70.9%	49.8%
	3	Josef-Bohmann-Hof	100.0%	74.9%	65.3%
	4	Friedrich-Engels-Platz	100.0%	83.7%	58.7%
Comparison Areas	5	Karlsplatz	100.0%	87.4%	79.9%
	6	Volkstheater	100.0%	87.0%	79.2%

Table 7: Comparing Job Accessibility within the neighborhoods – between transport modes (own elaboration).

The biggest differences **between transport modes within an area** can be found in case study area 2, *Atzgersdorf.* The job accessibility level by public transport is only half as high as by car and by bike it reaches 70.9% of the accessibility level by car. It must be pointed out that results for public transport are likely to be worse than for other modes, due to restricted working hours and waiting times at public transport stops, that are included in the travel times and thus have direct effect on the accessibility levels. Nevertheless, the figures indicate a substantial gap in the provision of transport services for case study area 2. They will be further explored in chapter 6.2. Case study areas 1 and 4 show good results in cycling, however case study area 4, *Friedrich-Engels-Platz,* has a relatively high gap when looking at public transport.

Finally, and in addition to the space-related and mode-related comparison approach, access across all modes and analyzed areas is displayed in Figure 23. It compares all accessibility levels for the areas and modes with the highest job accessibility level, which is by car for the comparison area *Volkstheater (marked in red).* The figure shows that job accessibility by bike and public transport in the best-off areas *Karlsplatz* and *Volkstheater* are partly higher than the one by car in the case study areas. Only looking at the numbers, that, as explained before, pose some limitations due to being only a model that is not able to fully reflect reality, this would mean that a resident in case study area 3 that depends on public transport, has a job accessibility level which is only about 40% of that of a car user in the central district comparison areas.

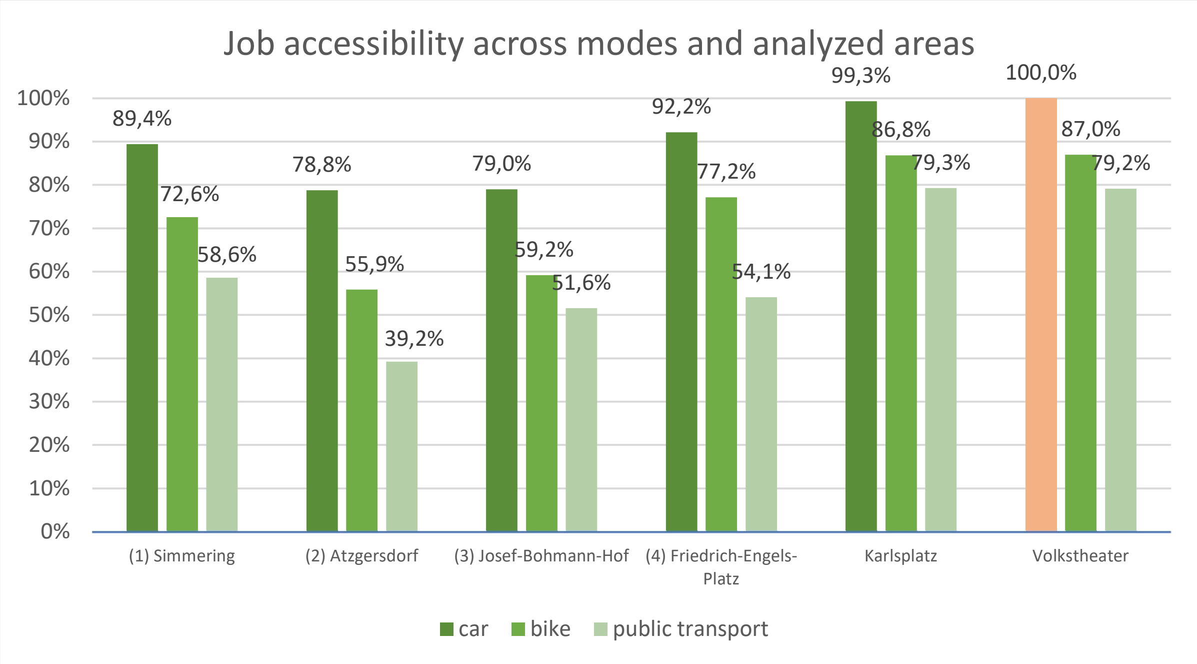

Figure 23: Job accessibility across modes and analyzed areas. (Own Figure).

5.2. Accessibility to centers from the Analyzed Areas

In addition to the analysis of job accessibility, accessibility to centers and central areas has been included into the research design. The centers and central areas chosen as destinations were defined according to the "*Polycentric Development Concept*" of the City of Vienna (MA18, 2020). Their rank, following the categorization provided in this concept, was drawn upon for the assessment of accessibility of those destinations (see chapter 4.2.2). Centers have been chosen, because they represent those locations in the cities, where a broad variety of services and goods are provided (*ibid*: 16). However, it must be acknowledged that this approach is sensible to a conflictive situation. Not only is accessibility to centers highly important, but also, the location and development of centers is highly dependent on its accessibility. Nevertheless, it is enriching to explore accessibility levels to centers and central areas, as it simultaneously represents accessibility to a broad range of activities.

Coherent to the calculation of job accessibility, the main conditioning factors for the results of center accessibility are *a)* the assessment of attractivity of destinations, according to the center rank (described in chapter 4.2.2) and *b)* the impedance to reach the destination, expressed in travel time.

The theoretical formula for calculating the indicators has been coherent to the one used by accessibility. Travel times per modes were evaluated in the same way as for jobs. The accessibility index (**A**) can again be understood as the sum of all products:

$$Ai = \sum_{j} D_j \; f(C_{ij})$$

A_i= Accessibility at Origin i
D_j = Destination (Center or Central area) j weighted by attractivity (rank)
f(Cij) = Mode-specific Impedance function
Cij = Travel time from Origin i to Destination j

Table 8 displays the results for accessibility to centers and central areas from the analyzed case study areas. The absolute index values are lower when compared to those of job accessibility, as significantly less destinations points were to be included into the analysis and thus the overall possible maximum sum is lower.

	ID	area_name	Bike	Car	Public Transport
Case Study Areas	1	Simmering	69.5	83	62.4
	2	Atzgersdorf	62.4	73.7	43.4
	3	Josef-Bohmann-Hof	55.6	72.8	55.9
	4	Friedrich-Engels-Hof	78.4	89.4	62.6
Comparison Areas	5	Karlsplatz	87.8	95.8	85
	6	Volkstheater	89.4	98	87

Table 8: Calculated Center Accessibility Indices – absolute index values. (Own elaboration).

In accordance with the procedure applied for job accessibility, firstly the space-related differences and secondly the mode-related differences for center accessibility will be discussed in the following paragraphs. Eventually a comparison across all areas and all transport modes is added.

5.2.1. Comparison between neighborhoods

The comparison between neighborhoods to address space-related inequalities in center accessibility, shows similarities to the findings in the previous section. Figure 24 displays center accessibility in the respective areas as percentage share of the maximum value for each of the transport modes. Again, center accessibility is highest form *Volkstheater (*see Table 8). Thus, all other areas are compared to the maximum accessibility index values reached by that area.

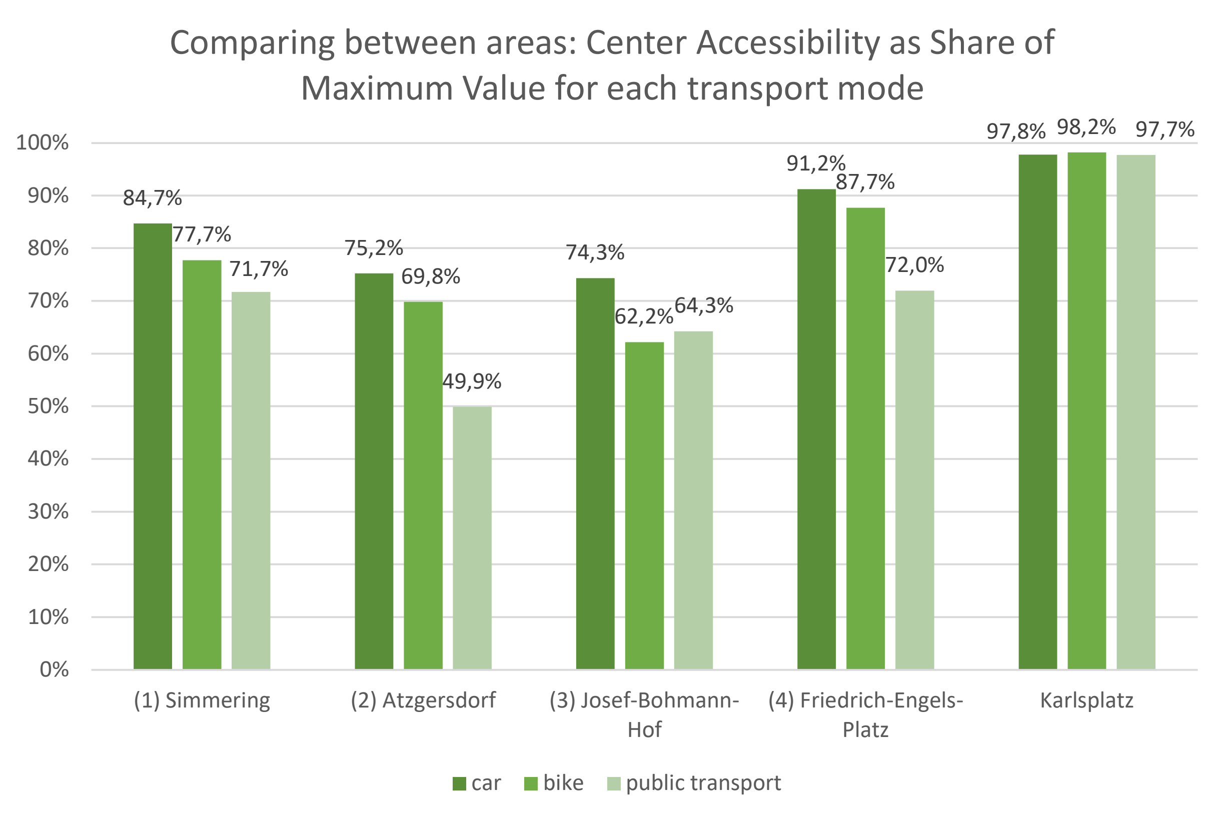

Figure 24: Comparing Center Accessibility between the neighborhoods. Share of index value reached by best-off area. (Own Figure).

In the case of accessibility to centers and central areas, the biggest gaps in the intra-neighborhood comparison can be found for **public transport**. Case study area 2, *Atzgersdorf*, again evidences lowest accessibility levels when compared to the others and only reaches half of the index value of *Volkstheater.* Comparing with job accessibility, it can be said that center accessibility by public transport performs slightly better in case study area 4 and slightly worse in case study area 1, *Simmer-ing*, which is the case study area that profits from a direct link to high-ranked public transport.

Center and central area accessibility by bike ranks second in terms of differences between the neigh-borhoods. Whereas in case study areas 2 and 4, bike accessibility shows significantly smaller gaps with respect to the comparison area *Volkstheater* than public transport, case study areas 1 and 3 reach similar shares for bike and public transport. It is remarkable that bike accessibility levels in case study area 3, *Josef-Bohmann-Hof*, perform better than public transit. It must however be kept in mind that a different impedance function was used for the different modes (see chapter 4.3.1).

Finally, concerning **center accessibility by car** in the different areas, it is evident that this mode again performs best and shows the smallest differences with regard to the comparison area *Volkstheater.* Unsurprisingly, the two case study areas 1 and 4, located closer to the inner city, perform better in terms of car accessibility than case study areas 2 and 3. However, the differences in percentage are a bit higher in the case of centers than in the case of jobs.

Summing up, the space-related comparison of center accessibility levels by different modes revealed that it is worst in case study area 2, *Atzgersdorf*, regarding public transit. Case study area 3, *Josef-Bohmann-Hof*, located north of the Danube River, however, performs worst when comparing car and bike accessibility levels to centers. Again, case study area 4 performs very well for car and bike accessibility but evidences a relatively bad result for public transit. Further implications of these findings will be reflected in the case study areas' reflective context (chapter 6).

5.2.2. Comparison between modes of transport

Accessibility to centers and central areas shows a similar distribution as job accessibility amongst modes of transport, in the sense that accessibility by car is highest in all studied case study areas. Table 9 displays the comparison between modes within each analyzed case study area. As center accessibility by car is again highest in all cases, it was pulled as comparison value for the comparison of modes in the respective area. Cycling and public transport are thus represented as percentage of the accessibility value reached by car.

			Comparing between transport modes		
			center accessibility		
	ID	area_name	car	bike	public transport
Case Study Areas	1	Simmering	100.0%	83.7%	75.2%
	2	Atzgersdorf	100.0%	84.7%	58.9%
	3	Josef-Bohmann-Hof	100.0%	76.4%	76.8%
	4	Friedrich-Engels-Platz	100.0%	87.7%	70.0%
Comparison Areas	5	Karlsplatz	100.0%	91.6%	88.7%
	6	Volkstheater	100.0%	91.2%	88.8%

Table 9: Comparing Center Accessibility within areas - between transport modes. (Own elaboration)

Comparing between modes, the highest difference within a neighborhood can be found in the case of *Atzgersdorf* (2), where public transit reaches only 58.9% of the accessibility level of motorized individual transport (car). This fact can have significant impact on the public transit-dependent parts of the population. The differences between modes for this area are however less striking than in the case of job accessibility.

Overall, public transport tends to perform better for center accessibility when comparing between modes, than for the case of job accessibility (see chapter 5.1.2), even in the comparison areas *Karlsplatz* and *Volkstheater.* This indicates the good connectivity of the centers in Vienna. However, two remarks must be made. Firstly, in case study area 4, *Friedrich-Engels-Platz*, and 2, *Atzgersdorf,* the performance gap between bike and public transport is significantly bigger than for all other cases.

Secondly, the similarity of results for center accessibility by bike and by public transport in case study area 3, *Josef-Bohmann-Platz,* is noteworthy.

Finally, comparing **across both modes and areas** (see Figure 25), case study areas 2 and 3 clearly show the lowest performance in center accessibility. All calculated accessibility indices have been compared to the best value, which is reached by car from Volkstheater (marked in orange) Public transit overall performs better for center accessibility than it does for job accessibility.

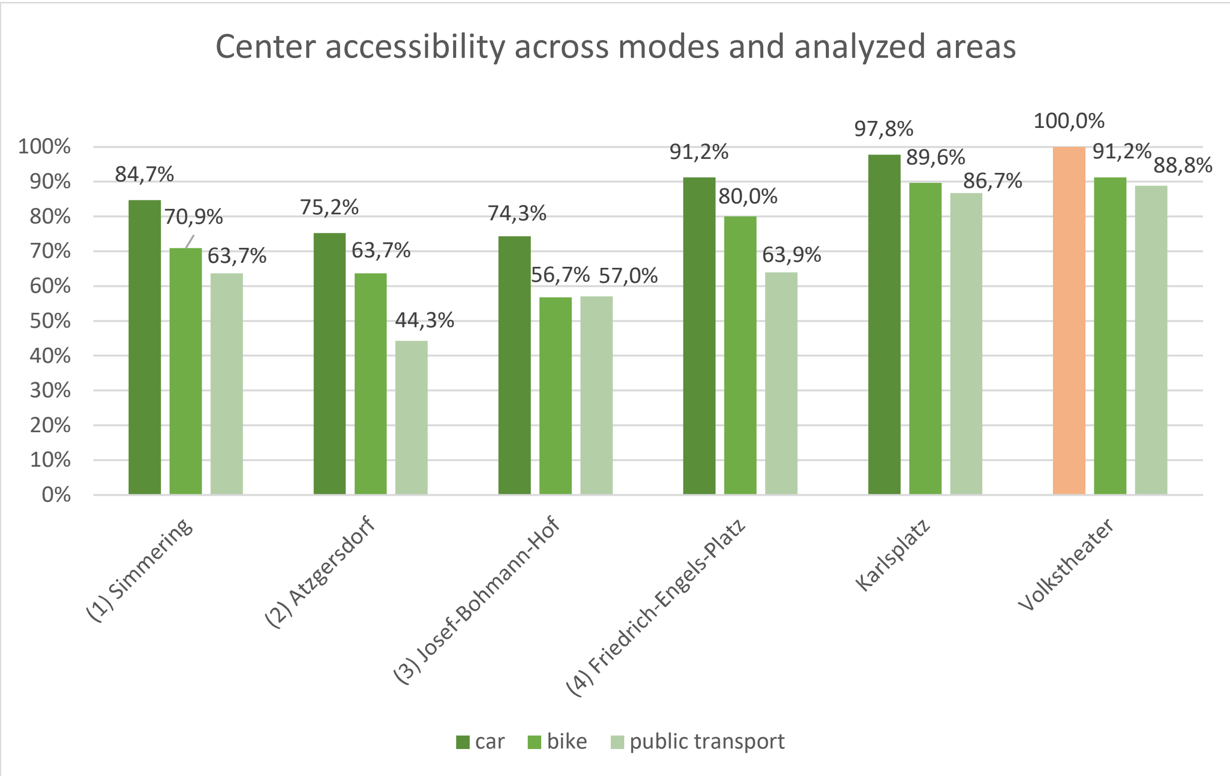

Figure 25: Job accessibility across modes and analyzed areas. (Own Figure).

5.3. Summary of the main findings

This section aims at shortly summarizing the discussed findings on accessibility indices to jobs and centers from the chosen case study areas. The goal is to answer the research question: **In how far does the accessibility differ between modes and areas in the analyzed cases?** Detailed discussions on the specific background and factors influencing the results are subject in the hereto following chapter 6.

Firstly, taking into consideration differences between the analyzed **modes**, results show that **motorized individual transport (car) performs best in both job and center accessibility**. This is followed by the mode cycling and lastly, public transport. The **mode-related differences in accessibility vary substantially between the analyzed cases**. Whereas the center accessibility index by public transport in the "best-accessible" comparison areas is close to 89% of that of motorized individual transport, case study area 2, *Atzgersdorf*, evidences a gap of 41% between center accessibility by car and by public transport. It is also noteworthy that case study area 4, *Friedrich-Engels-Platz,* has good performance in both job and center accessibility by car and bicycle, but relatively bad results for public transit. Generally, **mode-related distributions of accessibility levels tend to differ more in the case of job accessibility than for center accessibility**.

Secondly, when comparing **between areas** and looking at space-related equity, **important gaps in accessibility can be found especially when it comes to public transit and cycling**. Overall, differences in job and center accessibility between areas are most striking for public transport. For example, in case study area 2, *Atzgersdorf,* the accessibility to centers and jobs by public transport is 50% lower than in the best-off comparison area *Volkstheater.* On the other hand, accessibility levels by car never show gaps bigger than 25.7% between the "best-off" and the "worst-off area". This finding is especially relevant, as public transit-dependent population could thus be threatened by not being able to fulfill their mobility needs and reach the desired destinations (Banister, 2008). Unsurprisingly, **those case study areas located in proximity to the Viennese city center tend to have higher accessibility levels to both centers and jobs.** However, looking at the results in detail, allows to spot shortcoming for specific transport modes in the analyzed cases, such as disproportionally bad job accessibility by public transport for case study area 4, which is located closest to the center, or a good center accessibility level by bike when compared to public transport in case study area 3, *Josef-Bohmann-Platz.*

Before concluding this chapter, attention must be drawn upon the difficulty of comparing accessibility indices between modes. Firstly, public transport will always be unlikely to reach similar accessibility levels to car transport, as frequency and service hours always restrict the overall performance. The private car and bicycle are, at least theoretically, available at every time and travel times, whereas for public transport availability of services is strongly restricted at night and partly on weekends. Travel times at night were also included in the indices, however with less iterations as it would otherwise deteriorate results significantly (see chapter 0). Secondly, many aspects concerning car and bike accessibility cannot be adequately reflected in the model used to calculate travel times. For example, delays due to congestion or searching for a parking lot, or individual restrictions for using a bicycle (e.g., fear) would, in reality, lower accessibility levels of those two modes.

6. Evaluation of results in the respective context

There are multiple ways in which the design and organization of transport networks and land use systems can enhance exclusion. Amongst the most relevant factors are geographical and network reasons, physical barriers, the monetary cost of travel, time-based factors, or other individual barriers such as language or psychological barriers. Exploring and understanding which of those factors might be relevant for specific areas is key to address the distribution of transport benefits (Schwanen et al., 2015: 125). As this thesis ultimately aims at offering recommendations for the analyzed cases and for the city of Vienna, it is indispensable to take a closer look at the case study areas' context.

The levels of accessibility to jobs and centers and the related inequalities in their distribution have been discussed in chapter 5. In this chapter a more **qualitative approach** is taken to understand the results in the context of local circumstances. By doing so, the second research question "***Which factors most notably affect the degree of accessibility of the areas?***" will be answered, as far as possible with the available insights and data. The goal is to elaborate a basic understanding for the factors most notably influencing accessibility levels in the specific cases. However, an in-depth evaluation of all factors would demand for more extended research on this behalf.

Accessibility is influenced by **the spatial, transport, individual and temporal component** (Geurs & Van Wee, 2004; Martens et al., 2012: 684), as has been exposed in chapter 2.2.2. Different factors are attributed to each of these components. Thus, for the purpose of this research, they will roughly be discussed for each case study area one by one. Information included into this procedure encompasses the **location of the respective area** within the city and with relation to the analyzed destinations, **built environment variables**, such as density, built form, street design and physical barriers (Lucas, 2006: 627), **transport provision**, including mode availability and quality of services, and **socio-economic variables** (Neutens, 2010: 1622). The discussion of the most important factors (see 0) will be the underlying basis for the recommendations given in chapter 7.

6.1. Case Study Area 1: Simmering

Case study area 1 is located in the 11th Viennese district also called *Simmering*. Albeit being part of one of the outer districts, the case study area is second closest to the city center out of the chosen areas, evidencing a linear distance of 5.2km to the city center (*Saint Stephen's cathedral*). This case study area plays important role as part of the *Simmering* district subcenter. With 8.2 hectares size, it is the smallest case study area of the ones chosen for this research. The population density was in the range between 200 and 300 inhabitants per hectare, which is above the Viennese mean for built area of

129.5 inhabitants per hectare (MA18, 2020b). Exact numbers are not publicly available for this geographical scale.

The case study area *Simmering* is characterized by a **mixed use**, including mainly residential functions, but also retail, gastronomy, and a school. Figure 26 shows an orthophoto of the case study area and its immediate surroundings, with the district's main street bordering the area in the northeast and the railway tracks of the suburban commuter train passing east of it. Generally, the area denotes for a block structure, which is characteristic for Vienna. Within the limitations of the case study area itself (which were drawn according to the statistical unit; see chapter 4.1), also row developments and a small shopping center can be found. While the eldest buildings date back to before 1848, most developments within the case study area are from the second half of the 20th century (City of Vienna, 2021b). Amongst them are four **municipal housing developments** from the years 1957 (126 units), 1961 (69 units), 1976 (35 units) and 2000 (16 units) (Wiener Wohnen, n.y.). The southeast part of the area is currently under construction and will provide more residential units from 2022.

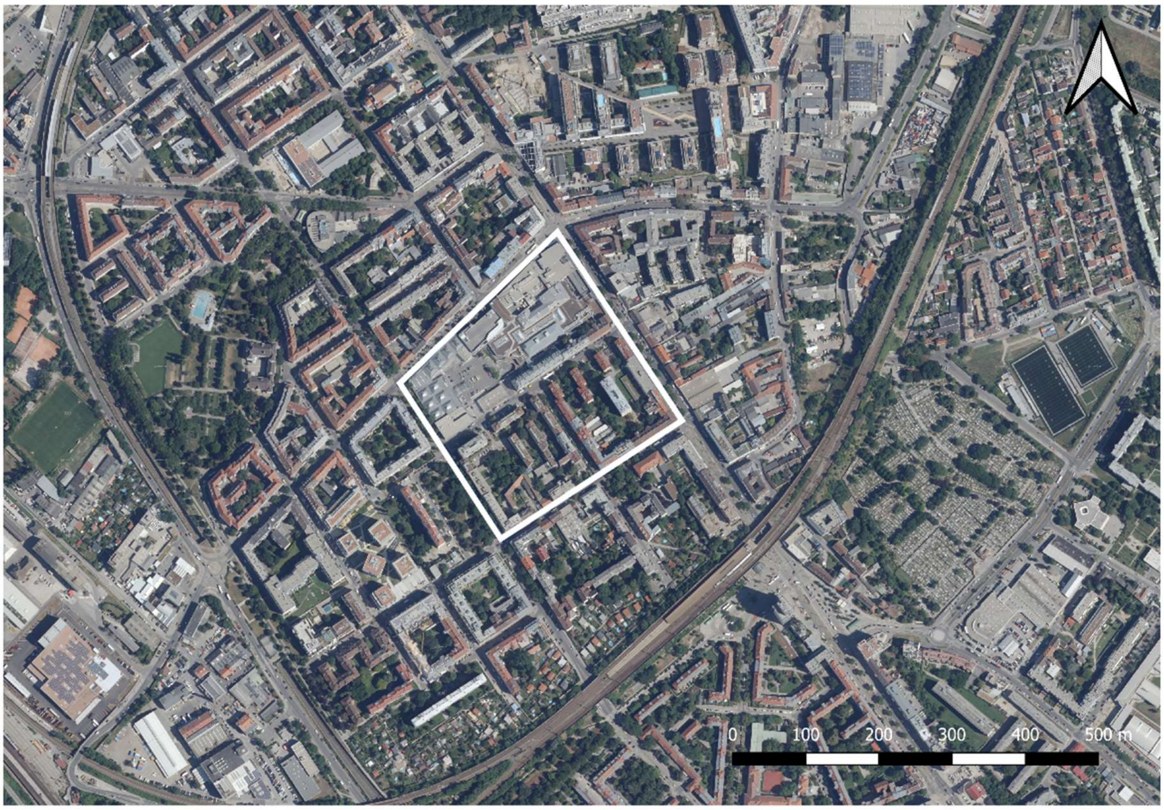

Figure 26: Orthophoto of case study area 1 – Simmering and the surroundings. (own elaboration based on basemap.at)

With respect to the **area's location within the city and in relation to centers**, it can be said that *Simmering* case study area is located in direct proximity to the main center of the district, "*Simmeringer Hauptstraße"*, which emerged from the center of the former municipality of *Simmering*. It thus has a character of a vibrant urban quarter (see Figure 27). According to the *Polycentric Development Concept*

(MA18, 2020a: 36), this center is to be further developed in terms of public space design, diversification of retail supply and improvement of fundamental central area functions. Another central area, "*Gasometer*" can be reached in a few minutes by bike, car, or public transport. Other centers are located farther west in the city.

Figure 27: Impressions of case study area 1 – Simmering. (Source: Author)

Regarding **proximity to jobs**, it can be said that the district of *Simmering* has traditionally been an **important industrial area**. With the construction of the railway passing the district, a strong industrialization of the district started already in the 1850s. Although many of the original factory locations disappeared after World War II, the district remained an important in-commuting district for workers. In 2016, there were 3,251 firms settled in the district, providing roughly 4,057 workplaces (MA8 & MA9, 2021a). Specifically, **case study area 1 is located amidst several commercial and industrial areas** and thus has **excellent prerequisites for achieving a high accessibility index level to jobs**. Other relevant jobs are located in the westwards direction towards the city center, but there are also some relevant industrial areas at the border of the city (east), already belonging to the federal state of Lower Austria.

Looking at the **transport component**, the overall good connection to all transport networks can be acknowledged. C study area 1 is directly borders the *Simmeringer Hauptstraße*, which passes through the whole district and connects it to the city center and thus offers good conditions for motorized transport. For public transport, this area is perfectly connected to high-ranked means, including the U3 line underground station Simmering, providing a westwards connection that crosses the inner city, and the train station Simmering, that connects to the main train station and the northern districts of the city. The tramway lines 71 and 11 operate along the *Simmeringer Hauptstraße* and offer an additional connection to the city center. Moreover, several bus lines (76A, 76B) pass the area.

In addition, there are **relevant factors that influence individual levels of mobility** but have not been included into the GIS analysis for reasons of complexity (Geurs & van Wee, 2004: 128). These include individual backgrounds and restrictions, but also for example the areas' provision with special mobility offerings. As already remarked, an in depth-analysis of individual factors is not possible within the scope of this research. However, some **socioeconomic indicators** available must be taken into account.

According to a survey on socioeconomic clusters in Vienna (MA18 & ZSI, 2013), the **area is characterized by population growth**, with many of the **new inhabitants having migration background**. Fluctuation of population is high, meaning that the structure is likely to change rapidly. The socioeconomic cluster analysis, has shown, that people residing in case study area 1, tend to be at **risk of income-related poverty**. Moreover, concerning the age structure of the area, with 21% of the population, there is a relatively **high share of elderly population above 65 years** (MA18, 2017).

Also, **car ownership** and additional mobility offering are likely to have great effect on accessibility experienced by individuals in the area (Lucas et al., 2018: 626f). In case study area 1, car ownership rates are in the range of 271-310 cars per 1,000 inhabitants. These figures are a bit below the Viennese average of 328 cars per 1,000 inhabitants but fit with the rates in the surroundings (BMI & MA18, 2019). Additional **mobility offerings** in the immediate surroundings of the case study area include a newly installed **"*WienMobil*" multimodal station**, that offers bike and car sharing (Wiener Linien, n.y.). Also, two **free-floating car-sharing companies operate in this area**, potentially expanding mode availability. However, other commercial mobility services, such as the e-scooter sharing systems that are functioning in the inner districts, are not available in or around the *Simmering* case study area.

Looking at the **results of the accessibility analysis**, it can be said that case study area 1 has an overall **good performance in intra-neighborhood comparison and acceptable gaps between modes when looking at intra-mode equity**. **Results for job accessibility are generally better than for center accessibility**, which is likely to be associated with the proximity of job locations and relative distance to most of the centers included in the calculations. Case Study area 1 stands out amongst all analyzed areas, by having the best accessibility levels achieved by public transport, which is little surprising considering the abundance of different means of public transport stopping in direct proximity. Also, the closeness to the subway and suburban commuter train systems, allow relatively good travel time performance at night, as it does not only rely on night busses with lower frequencies.

With respect to **cycling,** case study area 1 performs fairly well when compared to the central area control points. **Absence of slopes and a straight axis** leading to the center provide good conditions. However, site visits have shown, that the areas' surroundings would **profit from improvements in cycling infrastructure**, to increase bikeability and make cycling a more accessible mean for a broader group of people.

6.2. Case Study Area 2: Atzgersdorf

Case study area 2 is located in the **23rd Viennese district** *Liesing*, in the southwestern outskirts of the city. The linear distance to the city center (*Saint Stephen's Cathedral)* is of 9km and it is thus the case study area with the farthest distance to the city center. It has a total area of around 14.6 hectares and the population density is of between 200-300 inhabitants per hectare (MA18, 2020b), which is thus significantly higher than in the immediate surrounding. The character of the *Atzgersdorf* case study area is of a suburban residential area. Despite residential, few other uses can be found within the limitations, including a small grocery store and a snack bar. The built form in the case study area *Atzgersdorf* is by majority characterized by row development, with three municipal housing complexes being located within the case study area (City of Vienna, 2021). The oldest complex dates to 1958 (184 units), followed by a big complex from 1968 (336 units), and the last construction phase in 1977 (88 units). Figure 28 displays this built structure on the orthophoto of case study area 2 and its surroundings.

Figure 28: Orthophoto of case study area 2 – Atzgersdorf. (own elaboration based on basemap.at)

The **surroundings**, as well as some parts of the case study area are primarily characterized by detached houses and a **strong suburban character**, with abundance of green areas between the buildings of the complexes. As can be seen on Figure 29, street space is mostly allocated to motorized transport and little activities except for parking take place in public space. Generously designed parking lots depict that those neighborhoods were planned in an era, where access by motorized individual transport was at focus of interest. The connections within the housing complexes are intended to be for pedestrians only, but partly do not comply with modern requirements such as barrier free access. Moreover, there is a considerable slope within the area. This poses a challenge to the bikeability and influences the results of accessibility by bike, as the used ORS tool considers slopes as impedance in the calculations (Heidelberg Institute for Geoinformation Technology, 2021).

Figure 29: Impressions of Case study area 2 – Atzgersdorf. (Source: Author)

Regarding **proximity to centers**, case study area 2 is located between the three local centers of *Atzgersdorf*, *Mauer* and *Speising*, which are district level centers. All three were originally the centers of the previously to 1932 independent municipalities in the suburbs of the city (MA8 & MA9, 2021b). Moreover, the more important main center *Liesing* in terms of facilities and services, is located a bit farther, south of the chosen analysis area.

Looking at **the location of jobs** in the surroundings of the case study area, the following remarks can be made. Firstly, almost no jobs can be found the immediate surroundings of the case study area, due to the strongly prevalent residential use. Some job destination points categorized as "very attractive" (as described in chapter 4.2.2) can be found around the district centers mentioned in the previous paragraph. Moreover, important commercial and industrial zones and thus workplace agglomerations are located east of the case study area (see Figure 34 in chapter 0) However, this does not seem to have much influence on accessibility levels by public transport, as the neighborhood shows a significant gap between modes in job accessibility. This is likely to indicate lacking public transport links to the job agglomeration areas in proximity to the case study area.

Regarding the **transport component**, the case study area is not directly bordering a principal or main street and the job accessibility index **by car is 21% lower than in the best-off comparison point**. Nevertheless, motorized individual transport still performs significantly better than the modes cycling and public transport. Precisely looking at the **cycling infrastructure**, a tremendous gap in the provision can be evidenced in and around the case study area. There is no designated cycling infrastructure, neither within the case study area, nor in the immediate surroundings. Out of all case study areas, *Atzgersdorf* witnesses the biggest distance to the Vienna subway network. It is however, located relatively close to the suburban commuter train station "*Atzgersdorf*", where train lines heading towards the city center (north-south connection) stop with a frequency of roughly five to ten minutes. Walking distance to the station is of approximately 15 minutes from the center of the case study area. There are three bus lines passing by the area, of which two connect to this station as well.

As previously done for case study area 1, **socioeconomic indicators**, information on car ownership and mobility service provision have been included into the research. Regarding the socioeconomic composition of the case study area *Atzgersdorf*, two major clusters have been identified (MA18 & ZSI, 2013). On the one hand, part of the population has migration background and high risk of income-related poverty. On the other hand, especially within the municipal housing complex that dominates most of the case study area, a high correlation with unemployed Austrians (non-migration background) can be found. This group also has a risk of income-related poverty according to the study (*ibid*), albeit being lower than for people with migration background. The population is relatively stable, there is little fluctuation. Compared to other areas of the city, the population is relatively young (MA18, 2017).

Car ownership in case study area 2 is in accordance with the mean value for the city of Vienna, reaching a motorization rate of 310 to 363 cars per 1,000 inhabitants (BMI & MA18, 2019). However, when taking a look at the surroundings, an important differenc in car ownership can be identified. The car ownership rate within the case study areas is by far lower than in the surrounding neighborhoods. High car ownership rates in the surroundings give a hint on the relatively bad accessibility by public transport of the bigger area. **Additional mobility offerings are not to be found in the case study area**, neither bike or e-scooter sharing, nor car-sharing. No private operators have extended their business area to this part of the city.

Setting the **results of the accessibility analysis** in context with the provided information on the case study rea, the following deductions can be maid upon the relevant factors influencing accessibility. Firstly, *Atzgersdorf* case study area evidences the **worst results in both job and center accessibility.** Whereas motorized individual transport (car) shows the smallest gaps when compared to the other case study areas, significant differences must be acknowledged in cycling and public transport. This discrepancy indicates that the distance to the city center as well as the location within the urban fabric is not necessarily the decisive factor for levels of accessibility in the concrete case.

Secondly, important gaps between modes can be identified for case study area 2. Especially **public transport** performs weak, reaching accessibility levels to jobs and centers **50% lower than in the best-off comparison areas**. For cycling, center accessibility has reached better results, than for job accessibility. This can be set in relation with the geographical proximity of overall four centers or central areas, as previously discussed. Also, job accessibility by bike achieves better results than by public transport, possibly being a hint for a missing link to the commercial and industrial areas east of the case study area *Atzgersdorf*. At the time of the research, there was only one bus line connecting to that area.

Overall case study area 2 *Atzgersdorf* evidences the worst accessibility levels to jobs and centers amongst the analyzed areas. Especially the relevant **gap between modes of transport within the area should call practitioners to action**. Accessibility to jobs and centers by public transport is low compared to inner city areas and the other case study areas, when at the same time people residing within in the analyzed area experience risk of income-poverty and high unemployment rates (MA18 & ZSI, 2013). Albeit the relation between poverty, social exclusion and a lack of accessibility cannot directly be made (Kenyon et al., 2002: 209), several authors have highlighted that those factors could be mutually reinforcing each other (see chapter 2). However, developing recommendations is challenging for case study area 2, as the surroundings are rather wealthy suburban areas, with a prevalence of detached housing and thus low population density. This fact makes it harder to argue in favor of prioritizing the area for larger transport infrastructure investments.

6.3. Case Study Area 3: Josef-Bohmann-Hof

Case study area 3, *Josef-Bohmann-Hof*, located in the north of the city in the 22nd district (*Donaustadt)*, has a total area of 19.2 hectares. The linear distance to the city center (*Saint Stephen's Cathedral)* is of 7.6km. The population density ranges within the category between 200 and 300 inhabitants per hectare (MA18, 2020b). Most of the case study area is occupied by the municipal housing complex "*Josef-Bohmann-Hof",* as can be seen in the orthophoto in Figure 30). This municipal housing development was built between 1976 and 1978 and accounts for 1.238 housing units (City of Vienna, 2021). Albeit being one integrated development, the buildings were designed by different architects and thus show different appearances. The built form is of row developments, with relatively large green areas in between. A small pubic square (*Alfred-Kubin-Platz)* is located in the center of the neighborhood. The orthophoto also includes the subway station *Rennbahnweg* (U1) east of the neighborhood.

Figure 30: Ortophoto of case study area 3 Josef-Bohmann-Hof and surroundings (own elaboration based on basemap.at).

The case study area has a strong **residential character, with few other uses to be found within the quarter**. A school in the north and a kindergarten in the south can be found. Albeit those, only few retails and gastronomy are located around the central square. *Josef-Bohmann-Hof* only has two roads openly accessible by car, which lead to the central square from the north and east side of the quarter. However, it is not possible to cross the whole area by car. Big parking lots are provided in the western part of the case study area. The inner connectivity of the *Josef-Bohmann-Hof* was intended to be covered by mostly pedestrian paths, that wind through the generous green spaces between the rows of buildings (Gsteu, 2015: 245f). However, the design of the foot paths have turned out to be a matter of concern during the site visits. The safety feeling, especially at night, may be insufficient for groups of the population, due to the many corners and hidden spots that results from architecture and open space design. Overall, *Josef-Bohmann-Hof* conveys the feeling of a closed system with harsh limits to its surroundings.

Figure 31 provides some impression of case study area 3.

Figure 31: Impressions of case study area 3 Josef-Bohmann-Hof. (Source: Author)

With respect to the case study area's **location in relation to centers**, it can be said that it is located fairly far from the Vienna city center, accounting for almost 10km distance by car. It however shows proximity to a series of subcenters north of the Danube River. *Kagran*, a main center is located south-east of the neighborhood and along the U1 subway line, thus easily reachable from case study area 3. The two local centers of *Citygate* and *Großfeldsiedlung* are located north of *Josef-Bohmann-Hof* and along the U1 axis as well. Other centers can be found west of the case study area.

Looking at the **location of the area in relation to jobs**, the density of jobs within and directly surrounding the case study area is relatively low. Areas with important accumulations of workplaces are located west and northeast of the case study area, where major commercial and industrial zones are located, as well as along the U1 subway line axis (see Figure 34 in chapter 0).

The **transport component** in the case of *Josef-Bohmann-Hof* is to be described as follows. Generally, the area shows high affinity for motorized individual traffic (see Figure 30), although big parts of the quarter are traffic-calmed and only accessible for pedestrians and cyclists. For cycling infrastructure, a few marked lanes can be found in the surroundings. Most importantly, a physically separated bike path leads city-inwards along the U1 axis, which might be important for reaching various destinations. As for public transit, the U1 constitutes the lifeline of the area. It takes about 10 minutes walking from the *Josef-Bohmann-Hof* central square to reach the subway station *Rennbahnweg.* This allows to reach the heart of the city (*Saint Stephen's cathedral)* in approximately half an hour, including the walking time. Apart from the U1, only two bus lines pass by the area in the west (lines 27A and 31A). The latter allows to reach the commercial-industrial zone west of the case study area, whereas the other one connects to the one located northeast of *Josef-Bohmann-Hof*.

Similarly to the other case study areas, attention has been given to include further factors in this chapter, that could not be included in the GIS-model due to complexity. Firstly, looking at the **socioeconomic clusters** within the case study area, the following characterization can be made. On the one hand, part of the area is attributed to have a high probability of unemployed, a high share of migration and a high incidence of income-related poverty. On the other hand, another cluster within the area is characterized by absence of social problems such as income-related poverty or unemployment (MA18 & ZSI, 2013). The number of young people, below the age of 20, is very high in comparison with most parts of the city (MA18, 2017).

Case study area 3 has extremely low **car ownership rates** when compared to the surrounding areas and the city average, giving a hint at the deprived status of the neighborhood. The rate is attributed to be between 49 and 271 cars per 1,000 inhabitants (BMI & MA18, 2019). There are no mobility sharing services available in the case study area and no additional mobility offerings have been found. People not owning a car rely almost solely on the U1 axis or on the bicycle.

Looking at **results of job and center accessibility analysis**, this neighborhood shows the second worst overall performance, following case study area 2. Regarding job accessibility, it even has a slightly worse performance than case study area 2. This could either be explained through higher availability of jobs in proximity to the latter, or through the walking time calculated to the nearest car-accessible street from the different starting points in case study area 3 *Josef-Bohmann-Hof.* As mentioned, only two streets within the case study areas are accessible by car and available for parking. On the other hand, case study area 3 performs better in job accessibility by bike and public transport. Firstly, bike accessibility to jobs and centers ranks relatively good, as it is a flat area with many traffic-calmed streets. Though, a closer inspection of bikeability would be recommendable. For public transport, much of the performance can probably be attributed to the proximity to U1 line, although also a positive remark on the bus connections to the commercial-industrial zones must be made. Given the proximity of many jobs however, accessibility indices could be expected to be better. Increasing frequencies or checking which destinations seems necessary.

When looking at center accessibility, the case study area shows a bit worse performance than for job accessibility. It is noteworthy that center accessibility by bike is worse than in case study area 2, especially by car and bike. Moreover, it is remarkable that in intra-mode comparison, public transport performs even slightly better than bike, even though waiting times for public transport are included to the model. Being a potentially very bikeable area, a closer look should be taken at the development of centers in the north of the city and at their accessibility by well-established bike infrastructure.

6.4. Case Study Area 4: Friedrich-Engels-Platz

Case study area 4, *Friedrich-Engels-Platz* has a total area of 16 hectares. It is located in the 20th Viennese District (*Brigittenau),* which is counted as a central district due to its proximity to the city center, accounting for a distance of only 4.3km to the city center. Population density in this case study area is very clearly above the Viennese mean of 129.5 inhabitants per hectare, with above 500 inhabitants per hectare (MA18, 2020b). Figure 32 is an orthophoto of *Friedrich-Engels-Platz* and its surroundings. It evidences that the case study area is encircled by railway tracks, highways, and the Danube River, constituting important physical barriers in all directions, despite southwards, where the access to public transport is given.

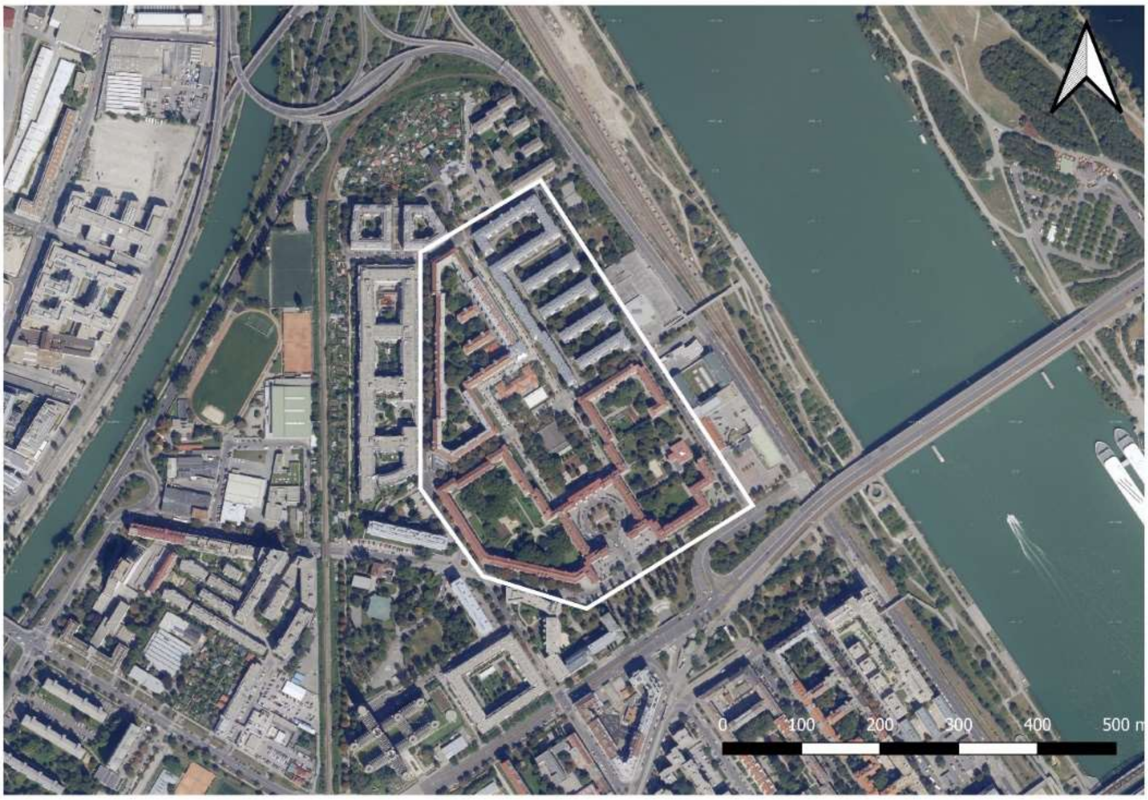

Figure 32: Ortophoto of case study area 4 Friedrich-Engels-Platz and surroundings (own elaboration based on basemap.at).

As can be seen, the case study area's built form is characterized by big-scale developments, that together form one big complex with a common square in the heart of it. The southern part of the case study area is the characteristic and heritage-protected *Friedrich-Engels-Hof*, a municipal housing complex erected between 1930 and 1933 and providing almost 1,500 housing units. It is a representative complex from the interwar "*Red Vienna*" period (MA8 & MA9, 2021). The northern part of the complex is occupied by another municipal housing complex, which was built in the 1950s and form-wise joins with the prior development. The area is of prevalent residential use, with only a few small stores and cafés to be found within the quarter. However, retail, including grocery stores, can be found in the directly neighboring blocks. Figure 32 provides some impressions of *Friedrich-Engels-Platz.* The area can be described as residential but with a more central and urban character than case study area 2 and 3, probably also due to its proximity to centers.

Figure 33: Impressions of case study area 4 Friedrich-Engels-Platz. (Source: Author)

Regarding the **location of the case study area in relation to centers and central areas**, case study area 4 is by far the most centrally located when compared to the other case study areas. The distance is about five kilometers walking, cycling or driving by car. However, the neighborhood is encircled by multiple barriers and case study area 4 is primarily accessible from south direction. Although the closest central area in terms of linear distance would be *Heiligenstädter Straße* in the neighboring 9th district, the *Friedrich-Engels-Platz* does not directly benefit from this proximity, as the two places are separated by the Danube Canal (see Figure 32). Other relevant centers in proximity are the center of *Floridsdorf* (across the Danube), *Brigittenau* and *Handelskai* (both in the 20th district). Thus, prerequisites for a high level of center accessibility are given.

Concerning **proximity to jobs and workplaces**, it can be said that albeit there are very few jobs to be found within the case study area, an important number of workplaces can be found in the direct surroundings. For example, in the 20th and 2nd district and in the neighboring 9th and 19th district (see

Figure 34). Also, the central area of *Floridsdorf* is an important job location and it is rapidly accessible thanks to the bridge connecting the two areas. The case study area thus has excellent preconditions for a high level of job accessibility.

Regarding the **transport component**, the case study area is somewhat conditioned by its location between the Danube River, Danube channel and several linear transport infrastructures (highway and railway tracks). Public transport stops are mainly to be found just south of the area, on Friedrich-Engels-Platz, where three tram lines in city center direction have their final stop and one tram line crosses to the northern part of the city. Moreover, one bus line connecting to the mentioned 9th district passes south of the case study area and one bus line has the final stop in the north of the case study area. Due to the concentration of public transport stops mainly south of the area, walking distances to reach them might add up considerably to public transport travel times, similar to the case of case study area 3. Concerning cycling infrastructure, the area is well connected to important cycling routes.

When it comes to **car ownership**, case study area 4 has **very low rates when compared to the city average**, being in the range of between 49 and 271 cars per 1,000 inhabitants. Differently to the other case study areas this is similar to the surroundings values. Moreover, case study area 4 profits from various sharing services. It is the only chosen neighborhood that has *CityBike* bike sharing station in proximity (at Friedrich-Engels-square, same location as the public transport stops). It is as well the only case study area with a commercial e-Scooter sharing company operating in the zone. Two car sharing companies comprise *Friedrich-Engels-Platz* in their business zone.

Looking at the **socioeconomic** circumstances according to the clustering conducted by MA18 & ZSI (2013), a strong correlation with high unemployment rates, especially amongst Austrians, and a relatively high risk of income-related poverty can be acknowledged. Moreover, many people have a migration background (*ibid*). Compared to other parts of the city, there is a high share of above 17 % of young people below the age of 20 (MA18, 2017) residing in this area.

Finally reflecting upon the **results of job and center accessibility analysis** in this context, the following remarks can be made. Firstly, case study area 4 has an **overall good performance in both job and center accessibility**. It evidences high access levels by car and bike, showing only slight differences to those levels of the best-off control points in the city center, and being ranked first amongst the case study areas with these modes. Especially for cycling, this is a notable result and a great chance as well. The flat topography of the surroundings can be a chance for further fostering this mode in the area.

However, especially in the case of job accessibility, **public transport performs bad in intra-mode comparison**. Whereas in *Friedrich-Engels-Platz* case study area, public transport reaches only 58% of the job accessibility levels by car, central city comparison points reach close 80% of car accessibility levels by public transport. Similarly, for center accessibility, car and bike reach excellent results, whereas the gap to public transport is notably high. It is, however, a bit lower than for job accessibility. Bad performance of public transport could originate from two main factors. Firstly, the area is not directly linked to a high-ranked public transport mode. Bus and tram lines usually have longer intervals, thus prolongating the calculated travel times. Secondly, as mentioned, the area is principally linked to public transit lines in the south section. People starting in the north of the area (expressed through the different starting points, see chapter 4.2.1), might have longer walking distances to cover.

Considering the size of the municipal housing complexes in this area, together with the fact that car ownership rates are fairly low, it can be argued that efforts should be made to narrow the gap between public transport and other modes. Yet it may be difficult to address this area due to the peripheral location and the physical barriers currently restricting access to and from the area.

Factors influencing accessibility levels in the case study areas

Having briefly discussed the results of job and center accessibility in the context of the case study areas, this section aims up at summarizing the factors that are likely to have biggest influence on the results. Neutens et al. (2010: 1613) point out the importance of questioning how the assessment of accessibility levels is affected by the exact measurement methodology used. Thus, highlighting factors influencing the travel time calculation results, is the first step. But reaching further, and as already partly done in the previous sections of this chapter, researchers and practitioners have to be aware, that there are relevant factors, going beyond those included in the calculation model, that have relevant influence on individual's accessibility. Both kinds of factors are included when trying to provide an answer to the second research question.

In a first place, factors that can be attributed to the **land use component** of accessibility will be summarized. As basis for the discussion and orientation for the reader, Figure 34 displays an overview map on centers and central areas, job locations and the location of the four chosen case study areas. As initially anticipated, the case study areas' proximity to jobs and central areas, being the analyzed destinations in the course of this thesis, has proven to be a relevant factor for achieving a higher level of accessibility. For example, case study area 4, *Friedrich-Engels-Platz,* evidences good accessibility to centers and jobs by car and bike, despite bordering several important barriers and being in a peripheral location within the district itself. It is however closest to the city center and those geographically closer to many of the central areas as well as to job agglomerations.

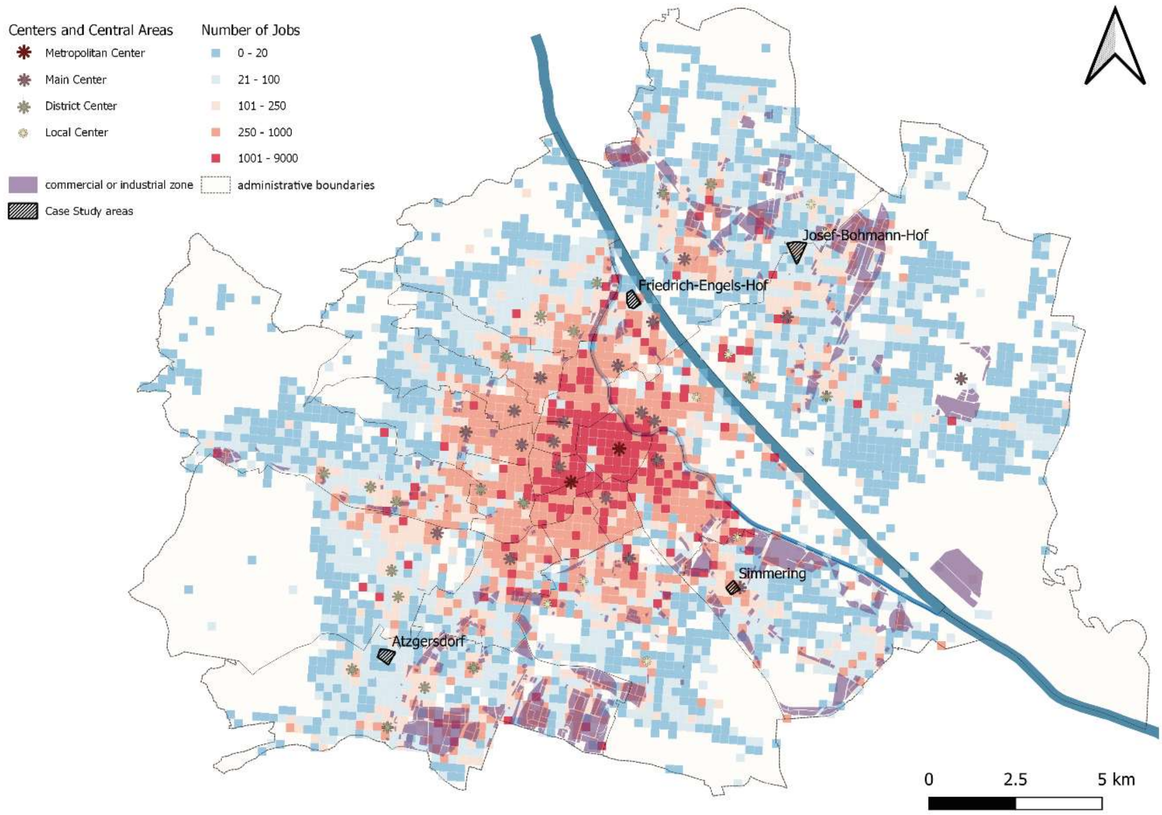

Figure 34: Location of Centers and Central Areas, Commercial / Industrial Zones, jobs and the case study areas. (own figure based on City of Vienna, 2021; MA18, 2020a; Statistik Austria, 2014)

On the other hand, the analysis has also proven that physical proximity to centers or job agglomerations is not a guarantee for better accessibility. For example, case study area 2, *Atzgersdorf,* which is in proximity to several centers of local importance, as well as to commercial industrial zones (see Figure 34) evidences bad results in both center and job accessibility, as the transport links are partly not well developed to those places. Also, case study area 1, *Simmering,* has good levels of center accessibility, albeit not being closely located to many centers.

Another factor that positively influences levels of accessibility from the land use component, is a <u>mixed use of areas</u>. This, of course, is closely related with the previously mentioned proximity to jobs and central areas. It must be highlighted that big housing complexes, with almost no other uses despite residential, tend to be less favorable for good performance in accessibility.

Lastly, the <u>built form and physical barriers</u> are important to mention. As discussed for case study area 3, *Josef-Bohmann-Hof*, the built structure of the large-scale municipal housing complex is challenging for accessibility, most notable for car and public transit. Having mostly pedestrian paths (equally used by cyclists) covering the inner access of the complex, residents need to cover bigger walking distances to reach their private vehicle (car or motorcycle) or public transport, which reflects in travel times and thus in accessibility levels. Moreover, physical barriers, such as in case study area 4, *Friedrich-Engels-Platz* significantly reduce the overall accessibility as they enforce detours.

With respect to the **transport component,** most obviously the provision of transport infrastructure and services is crucial for an area's performance in accessibility indicators. Not only the pure existence, but also capacity and quality of the services are important to mention. For this special focus was always laid on the importance of public transport and bikeability, as the city of Vienna has stated the goal to facilitate mobility without car ownership for all (MA18, 2015: 13), car ownership rates in Vienna are decreasing (Statistics Vienna, 2020: 15) and authors researching in the field of transport justice high-light the relance of public transport within the equity discussion (Gössling, 2016; Lucas et al., 2018).

A relevant aspect has turned out to be the walking distance to reach a means of transport. This is true for all analyzed modes of transport, despite only being acknowledged in the GIS model for public transport. Most notably, this factor is relevant for high-ranked public transport. Especially short walk-ing distances to high-ranked public transport stations have proven to be a beneficial factor for high accessibility levels, such as for case study area 1, *Simmering,* which profits from a subway city-inwards connection towards the West and a North-Southwest connection by suburban commuter train. Also, for case study area 3, the relative proximity to a subway station is highly relevant for accessibility levels, especially because many centers and jobs concentrate along this transport axis. This aspect is relevant for cycling and motorized individual transport as well, when the time needed to reach the respective vehicle is also considered in the calculation of travel times.

Another important factor is the availability of transport modes. Whereas for public transport this fact directly reflects in the results (through the departure times in the GTFS-dataset; see chapter 4.2.4), many studies and methodological approaches do part from the assumption that a bike or a car is avail-able at any time and directly at the location of start. However, even for households owning a car or a bike, availability is not necessary given all the time, as the vehicle might be shared amongst several people. Moreover, it is, especially in neighborhoods without individually dedicated parking lots, likely that the vehicle is parked farther form the place of residence or – more general – start of the trip.

On the other hand, accessibility levels can potentially be increased in areas, if additional mobility ser-vices, such as different types of sharing vehicles are provided by public hand or private companies. Whereas case study area 1 profits from different additional mobility services, case study area 2 and 3 do not have any additional mobility services available. Considering that residents of this areas have less-privileged socioeconomic background, the improvement of public transport or other complemen-tary mobility service provision, could be crucial to avoid mobility-related enforcement of exclusion.

Finally, many qualitative factors effect influence on the transport component of accessibility. Factors, such as the attractivity, design and safety feeling of transport infrastructure and services have a relevant impact on accessibility. For example, well-developed cycling infrastructure can help to allow more people to reach destinations by bike. Safety feeling is also a crucial factor for experienced accessibility levels by individuals (Lucas et al., 2018: 623). As outlined for case study area 3, *Josef-Bohmann-Hof,* this factor can constitute a potentially important restrictive factor for individuals, and especially for certain groups. The site visits effectuated during this research, have brought valuable insights into the importance of street and public space design on this behalf.

This finally leads to the broad range of **individual and temporal components** that affect accessibility but have not been assessed in detail in the course of this research due to the chosen location-based approach. Geurs and Van Wee (2004: 128) have pointed out that income, gender, educational level and individual available time budgets can be possible individual factors that influence accessibility to opportunities. As no questionnaires have been effectuated, a socioeconomic analysis was taken as reference for addressing the individual component (MA18 & ZSI, 2013). The chosen areas for analysis partly evidence unemployment and a high risk of income-related poverty, and this can have an impact on accessibility levels, especially when it comes to the question of car ownership.

Jeekel & Martens (2017: 53) point out that people who do not actively make the choice of not owning a car but are “car-less” due to circumstances (cost or abilities) are likely to be at risk of mobility exclusion. In fact, a study on quality of life in Vienna conducted in 2018, proved a correlation between lower income and less probability for car ownership. Within the two lowest income groups (lowest 40% of incomes) more than half of respondents did not own a car, whereas only 25% of households from other income groups did not own a car (Dorner & Verwiebe, 2020: 24f). This proves that providing good accessibility by public transport is an indispensable need, if social segregation is to be prevented (Bunel & Tovar, 2014: 1322).

The evaluation of the results in the respective case study areas’ context, has shown that taking a closer look at the specific circumstances and conditions is indispensable for giving recommendations. Location-based accessibility measures are only able to reflect some aspects of the accessibility experienced by individuals, which eventually is the important factor when talking about social implications of the interplay of urban transportation and land use. Site visits have brought valuable insights into the importance of street and public space design, that is likely to affect the individual component of accessibility.

7. Recommendations

Numerous arguments advocating for the need for inclusion of the concept of transport justice and for the implementation of accessibility-orientated planning have been elaborated in literature. They have been outlined in chapter 2.1.3. Adhering to the third objective of the thesis, this section aims at providing recommendations that help to address inequalities in the distribution of transport benefits. This last step will allow to answer the third research question leading this master thesis: "***Which recommendations can be derived for transport planning and land use policy in order to address and prevent possible inequalities of the accessibility in Vienna?***". The coherent objective defined in the forehead of the research was finding and developing adequate approaches to address inequalities in accessibility for the specific case study areas, as well as for the city level.

The calculation of accessibility indices to jobs and centers and central areas by different modes is the underlying basis for the derivation of recommendations. Deriving recommendations for actions form these results is essential for supporting a shift towards transport justice. Authors point out that accessibility is rarely favored as important policy outcome, even when data are good (Durantón & Guerra, 2016: 5). The suggested recommendations will thus derive parting from the evidence of the case study areas in Vienna but reach beyond, by including findings from the literature research as well. This chapter starts off with specific recommendations for the case study areas (7.1) and gives general recommendations for the city of Vienna in the following section 7.2.

7.1. Recommendations for the case study areas

The previous chapter 6 has proven, that **results must be treated differently according to the local context situation**. The calculated indices offer a good first insight into the distribution of transport benefits. However, multiple further factors must be considered before proposing specific actions. Some of them have already been discussed briefly.

When giving recommendations for the case study areas, the **goal is to narrow existing gaps in accessibility levels**, both in relation to inter-mode and inter-neighborhood comparison. It is indisputable that equal distribution in the sense that everyone in every location gets same level of access is impossible to achieve, as space is always divided into centers and periphery (Martens et al., 2012: 687). Nevertheless, assessing local accessibility is regarded to be key for a more just distribution (Lucas, 2006: 808f; Mullen et al., 2014). The question of what a maximum acceptable gap in accessibility could be, has been discussed in literature (see chapter 2.1.3), but goes beyond the scope of this research. What will eventually be provided instead, is list of arguments for setting priorities, such as for example if "communities of concern" (Golub & Martens, 2014: 15) are affected by lower accessibility levels.

In this master thesis, the four chosen case study areas include municipal housing developments within the drawn limitations. This poses a further argument for considering distributional questions for transportation benefits, although ensuring acceptable accessibility levels is equally important for free-market housing provision. Much emphasis is put on accessibility levels by public transport, as authors point out the importance of good public transport networks for achieving an equitable distribution of transport benefits (Foth et al., 2013: 3; Gössling, 2016).

Case study Area (1) – Simmering

Simmering case study area profits from good job and center accessibility and does neither evidence extreme gaps in the comparison between neighborhoods, nor in the one between modes. Due to the nature of the accessibility measure, accessibility by car is rated better than by public transport, but comparing the modal gap with other neighborhoods, it does not seem to be an urgent concern of unequal distribution. The excellent public transport connection and the proximity to many job locations, as well as to the district subcenter of Simmering, ensures good access to most destinations for the residents of the area. Nevertheless, the area is included as "*local planning focus area*" in the urban mobility plan (MA18, 2015: 45). This means that transport networks in this area are to be expanded and improved. It is recommendable, to **use accessibility measures to test, whether the planned projects benefit** those neighborhoods in the surroundings of the case study area that currently show worse accessibility levels.

The area evidences a good **bike accessibility** level as well. However, site visits have shown that further **enhancement of bikeability**, through improving street design and giving enough space to the mode cycling could improve individual accessibility levels by bike. It is to mention that a fast connection corridor towards the city center and towards east is planned, that should allow a direct and faster cycling connection to important destinations (City of Vienna, n.y.).

Moreover, the already implemented additional **mobility services**, such as the *WienMobil* multimodal station area are to be **further expanded**. Given that *Simmering* surroundings fulfill important district level center functions, the area shows great potential for acceptance of such offerings. Moreover, **incentivizing commercial sharing providers to extend their business zone** to the more peripheral, yet urban characterized centers, would bring benefit to individual access levels, as it could expand mode availability.

Lastly, the further development of the **central area functions of *Simmering* district center** is important, as the area is not in proximity to many other centers or central areas and there is an increasing share of elderly people residing in the area. It must be observed that the city of Vienna already tackles this topic for this center in the "*Polycentric Development concept*" (MA18, 2020a: 36).

Case study Area (2) – Atzgersdorf

Case study area 2 shows worst accessibility levels within this research and it is acknowledged to be an "*area with local challenges*" in the Vienna urban mobility plan (MA18, 2015: 45). Whereas car accessibility shows acceptable gaps when compared to other modes, this neighborhood stands out by the extremely **bad public transport performance**. When walking through the area, **a clear favorability for private motorized transport** can be identified. Setting this into relation with the social deprivation of the area compared to its surroundings, a clear issue of mode-related inequality (Lucas, 2006: 803) crystallizes. **Improving access to jobs and centers by public transport is to be set as priority.** Yet, this might be challenging since the case study area itself shows very different characteristics from its surroundings. It is far denser in terms of population and built structure and shows a less privileged socio-economic structure of residents. Big-scale investments on the short term are unlikely to happen, due to the characteristics of the surroundings.

Thus, the recommendation is to think of **micro-level approaches to improving residents' accessibility.** The provision of additional services, such as **local sharing systems**, or multimodal mobility stations, would be a feasible way to improve accessibility levels and have already been proposed by the city planning department for other similar cases (MA21, 2019: 24ff). Also, in terms of **bikeability**, the area still lacks any investments. A good **connection to the planned fast connection corridor** along the sub-urban commuter train line, that leads towards the city center will be crucial for the area.

In the case of *Atzgersdorf* it could as well be of importance to provide **better access to nearby job locations by public transport**. For example, east of the case study area is an important agglomeration of commercial-industrial zones, which by now do not have good public transport provision from case study area 2. Moreover, fostering **job creation in the southwest centers of the city** could be a preferable solution to avoid traffic and simultaneously increase job accessibility levels for people in the area.

Case study Area (3) – Josef-Bohmann-Hof

Case study area 3 has, despite showing second worst results in job and center accessibility, notably small gaps between public transport and bike accessibility levels. Job accessibility by public transit seems to be favored through the closely located U1 subway axis, and bus services that connect to job location areas in the surrounding northern parts of Vienna. However, given the geographical proximity, job accessibility could have been expected to even perform better, and thus there is room for improvement.

One specific challenge for the neighborhood is the built form and access logic. The inner parts of the area are by majority designed for pedestrians. No public transit lines cross the big complex and the closest high-ranked transport is more than 10 minutes walking-distance away from the central square of the area. Long walking distances within the block are likely to reduce accessibility for all modes, except for cycling, assuming that bike parking is possible at residence location. Thus, a recommendation is to check the options for providing any (public) **mobility service that directly crosses the area** and ideally **connects it to the U1 subway station** and **with central areas west of the case study area**. An example could be the small electric buses currently in use in the inner city of Vienna.

A second recommendation concerns the **interplay of the area with its surroundings**. Currently everything seems to be orientated towards the U1 subway line as main axis. However, in terms of accessibility to a broad variety of destinations, it would be desirable to **strengthen the central area functions in the surrounding centers** and to improve the connection to there. Further expansion of tramway lines in the north of the city, should especially focus on connecting big housing complexes, such as *Josef-Bohmann-Hof,* to local centers, especially if socio-economic deprivation can be identified, as given the case in *Josef-Bohmann-Hof*.

Lastly, a closer **revision of bikeability and walkability of the area** and its surroundings is highly recommendable. The already good performance of job and center accessibility by bike shows that further potential for improvement is given. Direct and well-designed infrastructure could allow to increase individual access level, especially for those without car ownership. As for walkability, the areas' design currently is likely to convey low safety feeling at night. As all modes are dependent on these factors, the safety issue should urgently be tackled, despite not influencing the calculated accessibility levels. Moreover, given the size of the housing complex, implementing different **mobility solutions specific for the complex** could **improve mode availability**. Currently, no **sharing services** are available. Implementing measures to improve accessibility in *Josef-Bohmann-Hof* is especially important, to avoid further spatial-social differentiation (Bunel & Tover, 2014: 1323).

Case study Area (4) – Friedrich-Engels-Platz

Case study area 4 has best overall access levels due to its location in proximity to the city center, but evidences striking gaps in mode-related comparison, indicating that public transport provision might be a matter of unequal distribution. Similarly to case study area 3, one main challenge is the lacking penetration of public transport lines within the big housing complex. However, in this case it would be easier to introduce for example a new bus route, as streets are open to car traffic. One recommendation is thus to check on options to **design an additional bus route through the area**.

Another long-term aspect to tackle, is the **barrier** function of surrounding linear infrastructure. Finding solutions to **better integrate this part of the 20th district** with the neighboring 9th in the south and 21st district in the north would probably bring profits not only to the analyzed case study area, but to neighboring areas as well. The good performance of bike again is a reason to further **foster the improvement**

of cycling infrastructure in the surroundings, especially as public transport performance is relatively bad when compared to other central areas.

To conclude, Table 10 shows an overview on the recommended measures to improve the case study areas' accessibility to jobs, centers, and central areas.

Measure	Simmering	Atzgersdorf	Josef-Bohmann-Hof	Friedrich-Engels-Platz
Transport related measures				
Improvement of public transport provision through additional lines				x
Better "infiltration" of public transport in the area			x	x
Revising bikeability	x	x	x	x
Revising walkability and safety feeling			x	
Fostering local mobility services		x	x	
Urban Planning / Built environment				
Enhance the development of centers in the surroundings	x	x	x	
Focus on Job creation in the surroundings		x		

Table 10: Summary of the recommendations for the specific case study areas (own elaboration)

7.2. Recommendations on city level

Albeit thinking of approaches for improvement of local accessibility levels is an important task of transport and urban planning, it is equally urgent **to implement accessibility metrics in planning on the city level.** This will contribute to the much-demanded shift from the established mobility paradigm to accessibility-orientated planning (see chapter 2.2.3).

In the case of Vienna, the results of the job and center accessibility analysis have evidenced that substantial differences do exist between different areas of the city. It especially depicts the need for addressing mode-related inequalities in the distribution of accessibility, both within and between neighborhoods. Tackling the social aspect of urban mobility, the city of Vienna already follows some remarkable approaches, especially when it comes to the fairer distribution of street space amongst transport modes, or to aspects of gender (see chapter 3.2). The latter is given much emphasis in Viennese planning documents (MA18, 2015: 45; 113f), acknowledging the differentiated individual demands for the mobility system. However, disregarding aspects of gender and diversity, no measure on the distribution of transport benefits has so far been introduced in Viennese planning, which leads to the first and main recommendation on this behalf.

7.2.1. Introducing an accessibility measure as standard planning tool

In order to prevent and ideally avoid inequalities in the distribution of transport benefits, and based on the experience from this research, it is **a strong recommendation to implement a GIS-based accessibility measure as regular control tool.** This will facilitate **the assessment of social implications of any future planned projects and scenarios**, as pointed out by several researchers (Boisjoly & El-Geneidy, 2017: 40f; Martens et al., 2012: 693; Pyrialakou et al., 2016: 253).

Certainly, taking the decision to implement such a tool would demand for initially high **financial and personal resources**, especially when setting up the GIS-model for the first time. Greater personal resources would allow to significantly **refine the model and gradually introduce more parameters**. For example, based on the learnings and shortcomings of this study, it is recommendable to include multimodal trip modelling into the tool, treating it as additional transport mode. Moreover, it should cover the whole city area, and ideally even surrounding municipalities. Thus, making use of current technological possibilities, that includes GTFS data and rapid developments in user-friendly tools for network analysis, holds great **chances for better assessment of complex concepts, such as that of accessibility**.

Even though no model will ever be able to fully reflect all aspects that influence individual accessibility levels, the implementation of an accessibility measure would help to **make inequalities more tangible**. It could be a powerful possibility to **make social implications of transport benefit distributions visible and understandable**. Providing local decision-makers with improved information on the areas with poorest accessibility levels is crucial (Lucas, 2006: 804) to address the issue.

Having the respective GIS-model regularly updated and maintained would allow planners in Vienna to **assess projects and plans in the fields of transport planning and urban planning from the transport justice perspective**. For example, it would be relatively easy to investigate which neighborhood would profit most from planned measures in terms of accessibility levels and to check, whether plans can contribute to reducing inequalities in the distribution of transport benefits.

However, the proposed accessibility tool is to be understood as just the first step when addressing inequalities. It is a useful tool to rapidly identify potentially disadvantaged neighborhoods, but as pointed out in chapter 0, **several additional factors, such as socioeconomic circumstances of residents, car ownership, or quality of public space design must be taken into account before deciding on priorities for taking action**. The introduction of an accessibility model as "justice control tool" must not replace bottom-up and participative decision-making processes (Lucas, 2006: 805).

7.2.2. Adopting accessibility goals and indicators

Secondly, **transport justice and coherent performance indicators should ideally be adopted by decision-makers and the Vienna municipal administration**. Already reaching outstanding performance in international comparison, the Viennese transport network, and its interplay with land use, is in the position to envision long-term goals concerning transport justice. Important steps, such as giving greater consideration to active and public transportation (Banister, 2008: 39), have already been initiated in the Urban Development Plan *STEP2025* and in the Urban Mobility Plan (see chapter 3.2). However, there is room for improvement, when it comes to understanding and addressing inequalities in the distribution of transport benefits.

Ideally, transport justice could be seen as long-term goal and part of the welfare-state, such as the health or educational system (Jeekel & Martens, 2017: 8). **Specific benchmarks** could be set, such as a maximum range of acceptable differences between neighborhoods and modes, similar to the "maximax" ethic proposed by Martens et al. (2012: 693f; see chapter 2.1.3). Another goal should be **that no measure should contribute to a significant widening of the gaps in accessibility** between the best-off and the worst off. That being the case, corrective measures ought to be found.

Finally, it is left to point out that goals must be adopted with **specific and measurable indicators**. If not, there is a high risk of using accessibility only as a buzzword (Boisjoly & El-Geneidy, 2017: 44f). It is also highly relevant to choose indicators that address accessibility and not mobility (e.g., travel time alone, or distance from transport stops). Indicators like the index developed in this thesis could be thought of.

7.2.3. Other recommendations

The Viennese Urban Development Plan *STEP2025* and the urban mobility plan have defined the goal to shift Vienna's mobility towards more eco-friendly modes of transport and to maintain a "*sustainable and equitable mobility system*" (MA18, 2015: 13). This is not to be reached through a single policy measure, but rather through a **coordinated set of measures in transport, housing provision and land**

use planning (Buehler et al., 2017: 12). The following paragraphs offer further recommendations that ought to be considered for tackling the distribution of accessibility levels throughout the city.

Fostering mixed land use

Trying to reduce distances between different activities through the allocation and mix of different land uses, is essential to the distribution of accessibility levels. It is a principle already pursued by Viennese planning practice (MA18, 2015: 84). In some cases, the improvement of local provision with a broad variety of services is likely to have more impact on accessibility experienced by individuals, than improved transport links.

Improvement of the cycling network

Although results of job and center accessibility do not indicate substantial inequalities, site visits have proven that the aspect of bikeability is of indisputable importance for the areas. Buehler et al. (2017: 13) remark that cycling infrastructure in Vienna remains less well-connected than in comparable German cities and evidences an overall lower quality. Thus, the good performance of biking in the GIS-based analysis is understood as hint for the future potential of cycling in these areas. Especially in the northern and eastern parts of the city, where topography is perfect for cycling, bigger effort should be laid on establishing high-quality cycling infrastructure. Priority should be given to connections between central areas, jobs and residential locations with high population densities, especially big housing complexes.

Micro-level solutions

An aspect discussed in literature and evidenced in the case study areas, is the problematic interplay of income and accessibility levels. According to Nazari Adli & Donavan (2018: 57), low-income households can be expected to be concentrated in areas that experience lower levels of accessibility, while simultaneously having higher probability of not owning a car, as found in the case of Vienna (Dorner & Verwiebe, 2020: 24f).

Especially in big housing complexes, such as the ones analyzed, it would be useful to think of implementing solutions on the local level. Sharing systems – if not offered by commercial providers – could be a way to extend mode availability for residents and thus to increase accessibility levels. Another alternative could be on-call minibus systems, similar to those already provided in some parts of Vienna (Wiener Linien, 2020).

For some areas it could be a viable solution to have specific transport services partly financed by relevant employers. However, more insight into commuting-patterns and travel demand would be needed to realize such an option.

Further improvement of the public transport network and services

In order to facilitate mobility without a car for all groups of the population and in all parts of the city, further extension of public transport routes and improvements of services are already envisioned by local transport providers and the city municipality. Special attention should be given to the social implications of future investments in transport infrastructure. Using a tool as the one proposed for evaluating the effects of new infrastructure would be desirable to better tackle the topic of transport justice. In this context it is important to acknowledge that new or additional travel alternative's impact on accessibility may vary substantially, depending on how well-developed the offer was previously (Duranton & Guerra, 2016: 23).

Many other aspects could be further listed as recommendations and many factors are still left for further investigation. Amongst them are the exploration of how the individual component influences different groups within Vienna, the impacts of different legislations, subsidies' and taxes' effect on accessibility for individuals, or the importance of sharing services for increasing mode availability and eventually accessibility levels.

8. Conclusion

The design and functioning of transport networks inevitably lead to an unequal distribution of benefits and burdens amongst the population, be it freedom of mode choice, ability to reach desired activities, health impact or accident risk. The aim for gaining insight into the social implications of transport networks, has given rise to the research field of transport justice, which focuses on distributional questions of both transport benefits and burdens, especially in the urban context. With respect to the positive effects, accessibility, the ease of reaching destinations, is acknowledged to be the main benefit, as eventually all trips have the purpose of reaching a specific destination or activity.

The literature research effectuated prior to the empirical analysis of this thesis, has proven that the relation between insufficient accessibility and a higher risk of social exclusion has been analyzed by several authors, both theoretically and in specific cases. However, little research on this behalf has been conducted in the Central European context and in Vienna. Whereas equity and fairness are envisioned as goals for future urban mobility in Viennese planning documents, no direct link to specific accessibility indicators or goals is made.

Hence, this thesis aimed at addressing the gap in literature and planning practice by approaching transport planning in Vienna from a justice-orientated perspective. Based on the assumptions on potential impact of accessibility on people's life opportunities, the following three research questions have been elaborated and answered for the case of Vienna:

- *In how far does the accessibility to jobs and centers and central areas differ between the analyzed areas and between transport modes?*
- *Which factors most likely affect the degree of accessibility in the areas?*
- *Which recommendations can be derived for transport planning and land use policy, in order to address and prevent possible inequalities in accessibility in Vienna?*

The questions have methodologically been approached by assessing the accessibility levels to jobs and centers of four selected case study areas. A location-based accessibility measure was chosen, accounting for all destinations within the city, and discounting for travel times. The destinations, jobs and centers and central areas, have been weighted according to their attractivity. A GIS-model was set up for the calculation of travel times from the case study areas to those destinations. It included the modes cycling, car and public transport. Results on accessibility levels have further been discussed in the case study areas' specific context, aiming at gaining a deeper understanding of critical factors influencing the accessibility levels.

Results

The analysis has proven that substantial **differences in job and center accessibility levels** can be found. Whereas accessibility levels by motorized individual transport (car) differ little between areas, greater gaps must be acknowledged in cycling and public transport. Especially accessibility levels by public transport show biggest differences between the case study areas. Considering the distinctive importance of public transport for those groups of the population that do not have a car or bike available due to a series of possible reasons, this finding reveals possible inequalities in the distribution of transport benefits that ought to be addressed. These mode-related inequalities also manifest clearly in the comparison within a case study area, where public transport accessibility levels tend to be significantly lower than by other modes. The gaps between modes show important variations depending on the area studied.

Analyzing the specific circumstances of the chosen case study areas has allowed to give an insight into **relevant factors influencing accessibility levels**, and thus to answer the second research question as following. For both job and center accessibility, the geographical proximity to centers and central areas with mixed uses is of major importance for good performance in the analysis. Unsurprisingly, the availability of high-ranked public transport stops does also lead to higher levels of accessibility, as jobs and centers tend to develop there, where transport links are good. Further identified factors in the analyzed cases are, most importantly, the built form and the design of pedestrian paths within areas and the local topography, especially for cycling. Moreover, factors such as walkability, bikeability, and car ownership are likely to have a big impact on accessibility levels experienced by individuals. Further research is needed to gain more certainty about the degree of influence of different factors to accessibility levels.

The **main recommendations** derived from the findings are the following. Firstly, accessibility measures should be established as permanent control indicator in Viennese planning practice. Setting up a suitable model, similar but more refined than the one developed in this thesis, would allow to test planned interventions' effect on accessibility levels and thus allow to better assess distributional effects. Secondly, transport justice should explicitly be addressed as political goal, and coherent indicators (e.g., accessibility to jobs or other destinations of interest) should be adopted to monitor the performance. Finally, this thesis has proven the importance of tailoring approaches to the specific cases in order to improve accessibility levels. Many relevant factors are too complex in reality, to be adequately incorporated into the model (e.g. design quality of street space), but have relevant influence on people's experience.

A general **assessment of accessibility levels is a feasible way to continuously monitor the social implications of planning decisions** and scenarios and allows to **identify gaps in accessibility**. Aiming at transport justice, results should be interpreted in the context of social background of the neighborhoods. The main goal should be to avoid strengthening social exclusion due to insufficient levels of accessibility to important destinations.

Outlook

Although the scope and the methodological approach of this thesis only allowed to give a first insight into the existing inequalities in the distribution of transport benefits in Vienna, the research was able to illustrate important gaps in accessibility. Simultaneously, it evidenced that **additional research** is to be conducted in order to better understand the distribution of transport benefits and its implications. On the one hand, **expanding the analysis to the whole city area**, which has not been done for reasons of capacity in this thesis, would allow to better understand the range of distribution throughout the city. On the other hand, **special focus** should be drawn upon **areas of social concern** and on big residential complexes. Further **investigation of individual and temporal factors** that may restrict accessibility levels in those specific cases could be valuable to improve the local situation.

Summing up, initiating a discussion on transport justice in Vienna can certainly said to be important and valuable for future transport and land use planning. It must be acknowledged that the city of Vienna has an outstanding performance in many domains when compared to other European cities. Also transport provision, most notably the public transport network, is known to be well-developed and further improvements are constantly aspired. Nevertheless, the analyzed cases have shown that some groups with weak socio-economic background are likely to experience lower levels of accessibility, which might have a relevant impact on people's life opportunities. Thus, becoming aware of the distribution of transport benefits amongst population groups and across the city, is key to maintain the status as one of the most liveable cities and to prevent segregation processes.

9. Reflection on the work

This chapter is intended to be a short reflection on the effectuated work after having completed the thesis. It is relevant to add some critical remarks on scope, methodology and chosen approach of the research. Some of those aspects have already been mentioned in the different chapters of the thesis, however this section will summarize the author's thoughts on the research design, methodology and implementation.

Starting with some **remarks on the chosen methodology,** the first concerns the decision of applying a **location-based approach** as described in chapter 2.3.1. This approach, which allows to calculate accessibility levels for geographically delimited areas rather than for individuals, is commonly used for the assessment of accessibility. In the case of this thesis, it was mainly chosen due to the initial aim to reflect distributional inequalities in accessibility, independent from who is living there and what the demand could be. Whilst adhering to this basic idea, the application of the methodology has proven that **the location-based approach does not cover a broad range of temporal and individual factors** (Lucas, 2006: 805; Neutens et al. 2010: 1617). Also, many **qualitative factors**, such as for example safety feeling at night, or the attractivity of public transport vehicles and stations, amongst numerous others, are also not included in this approach due to complexity. However, the reflection on the case study areas' context has proven that **experienced accessibility goes far beyond measurable indicators**. Although the location-based approach still seems suitable for the research question answered in this thesis, the shortcomings of the methodology make the deduction of specific recommendations challenging.

An effort to **make up for the shortcomings of the location-based approach has been made through adding a qualitatively approached chapter** (chapter 6) before concluding the research. It is important to repeat, that calculated accessibility levels must be interpreted within the local context. Based on the theoretical outline presented in chapter 2, most people will agree that bad results in accessibility levels are to be understood differently in areas of concern, or – as extreme opposite – wealthy suburban areas with detached housing, where it can be assumed that people deliberately choose to opt for a worse accessibility in order to profit from other benefits. The qualitative reflection of the results has given a first notion into that relativity of results. However, it must be critically remarked that this part of empirical work would have to be conducted more precisely to gain a deep understanding for the respective situations and challenges.

Another **limitation to this work** is the fact that the **demand side has not been studied** for the analyzed case study areas. Albeit this is coherent with the regular approach for accessibility analysis, as presented in chapter 2.3, it is hard for practitioners to argue for investments without considering the real demand for transport services. Whereas some argue that the essence of transport justice is to provide equal opportunities independently from who is living there and thus not depending on the demand (Jeekel & Martens, 2017), others criticize the "*assumption of high mobility*" (Sager, 2005:6). This would demand not only for perfectly allocated activities and perfect connections between them, but also for perfectly informed and mobile passengers.

In this context, another consideration concerning the demand side, are the **possible effects of the COVID-19 pandemic on mobility**, especially on commuting. The exceptional circumstances during the last months have spurred up a wave of digitalization, with increasing opportunities to work from home and thus allowing to increase job accessibility by digital means. Albeit the potentials of information and communication technologies have been acknowledged years ago (e.g., Miller, 2005: 63), COVID-19 has initiated a potentially long-lasting change. However, it is indisputable that physical presence and contact with others will never be fully replaced by digital meetings, especially in leisure and cultural activities. Thus, decent levels of accessibility to destinations will remain an important asset for communities and individuals.

There are, moreover, several **remarks on the implementation of the methodology** that ought to be made. Firstly, as has been mentioned multiple times throughout the thesis, the **GIS model**, albeit being built up in the most consciously and best feasible way, **does not reflect many aspects** of reality. For example, it does not consider the capacity of infrastructure, which may have effect on travel times, but also on comfort levels.

Secondly, **the selection of destinations** is highly relevant and can be criticized. Jobs, on the one hand, are frequently addressed in transport justice related studies, as participation in working life is assumed to be crucial for full participation in society. However, as lifestyles are becoming more diversified, it is arguable that job locations may be losing their primary importance. Centers and central areas on the other hand, have proven to rise several complications in the accessibility analysis. This was because centers are likely to develop where accessibility is high and efforts to increase accessibility to central areas is made simultaneously. If this research was to be effectuated for other cases, the consideration of other destinations would be recommendable.

Thirdly, pre-assumptions to the calculation have been made for practical reasons but pose important limitations to the results. An important aspect to consider is that the analysis has been **limited to the administrative boundaries of the city of Vienna**, due to the availability of data, especially for the public transport network information (GTFS-datasets). However, especially in the outer districts, job locations, but also centers in the surroundings of the citiy, are likely to be important and increase the range of accessible opportunities.

Concluding with some positive remarks, it can be said that the **scope of the research has been well defined**. Although parts of the literature research had been effectuated already in 2020, most of the empirical and the writing process has happened between March and September 2021. Within these six months it has been possible to answer the three previously established research questions to a satisfactory degree. As has been mentioned in the definition of limitations to the research (in chapter 1.3), the challenging question of how a "just distribution of transport benefits" could be, has deliberately been left out in this research. It would not have been possible to answer this question properly with the given personal and time resources. Approaching this task for Vienna (or more generally) would demand for an own extended research or analysis.

Lastly, it can be said that albeit evidencing multiple shortcomings or room for improvement in the analysis, the **chosen approach has given the chance to obtain a first tangible basis for the discussion on distribution of transport benefits in Vienna**. Although results cannot be interpreted in absolute terms, and the assessment of accessibility levels by different modes is an indicator that should be considered when modelling land use and transport policies. Through comparing both between areas and transport modes, the analysis has evidenced that indeed certain groups, especially those not owning a car, can be at risk of experiencing exclusion, partly due to lack off accessibility. Especially in cities such as Vienna, where quality of life is high in international comparison, it is important to keep track on issues of social equity.

Final personal remarks

This master thesis is the final piece of the **Double Degree Program** between **TU Wien** and **Tongji University Shanghai.** The basic direction of the thesis topic was already settled in 2019, during my stay in Shanghai, which was abruptly finished by the COVID-19 pandemic. Initially, the idea was to analyze accessibility and demand for various neighborhoods of Shanghai, making use of a more qualitative approach. However, since returning to Shanghai for effectuating empirical field work has not been possible throughout the year 2020 and 2021, I made the decision to adapt the topic and apply the research to the case of Vienna. The research questions and the methodology have changed significantly during this process of adaption, finally leading to the master thesis at hand. The process of developing and applying the empirical part of the research has been highly interesting and enriching and I can say that the thesis has been accompanied by an important personal learning process.

10. Bibliography

ASFINAG, n.y.. S1 Tunnel Lobau Visualisierung. Retrieved on August 2nd 2021 from https://www.asfinag.at/verkehrssicherheit/bauen/bauprojekte/s-1-wiener-aussenring-schnellstrasse-neubau-schwechat-bis-suessenbrunn/.

Banister, D., 2008. The sustainable mobility paradigm, Transport Policy Vol. 15 (2): 73-80.

Basso, F.; Frez, J.; Martínez, L.; Pezoa, R.; Varas, M., 2020. Accessibility to opportunities based on public transport gps-monitored data: the case of Santiago, Chile, 2020-10, Travel, behaviour & society Vol.21: 140-153.

BMI & MA18, 2019.: Bevölkerungsevidenz Oktober 2019. Retrieved July 2nd 2021 from https://www.wien.gv.at/stadtentwicklung/grundlagen/stadtforschung/karten/mobilitaet.html.

bmk - Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology, 2021. Austria's 2030 Mobility Master Plan. Retrieved July 20th2021 from https://www.bmk.gv.at/themen/mobilitaet/mobilitaetsmasterplan.html.

Boisjoly, G.; El-Geneidy, A., 2017. How to get there? A critical assessment of accessibility objectives and indicators in the metropolitan transportation plans*,* 2017-04, Transport Policy Vol.55: 38-50.

BPWW, Biosphärenpark Wienerwald, n.y.. Variety of Nature. Retrieved July 18th2021 from https://www.bpww.at/en/node/184 .

Buelher, R.; Pucher, J.; Gerike, R.; Götschi, T., 2017. Reducing car dependence in the heart of Europe: lessons from Germany, Austria and Switzerland, 2017-01, Transport reviews Vol. 37 (1): 3-28.

Bunel, M.; Tovar, E., 2014. Key Issues in Local Job Accessibility Measurement: Different Models Mean Different Results, 2014-05, Urban Studies Vol. 51(6): 1322-1338.

City of Vienna, 2021. Open Data. Wep Map Service. Retrieved on April 8th from https://digitales.wien.gv.at/open-data/

Die Presse, 2018. Räder von ofo und oBike solen noch im Juli aus Wien entfernt werden. Retrieved on July 20th, 2021 from https://www.diepresse.com/5466166/rader-von-ofo-und-obike-sollen-noch-im-juli-aus-wien-entfernt-werden .

Dorner, J.; Verwiebe, R., 2020. Lebensqualität in einer wachsenden Stadt: Stadtentwicklung, Mobilität und Umwelt. Teilbericht an die Stadt Wien. Wien: Universität Wien, Institut für Soziologie. Retrieved on August 4th2021 from https://www.wien.gv.at/stadtentwicklung/studien/b008577.html.

Duranton, G.; Guerra, E., 2016. Developing a Common Narrative on Urban Accessibility: An Urban Planning Perspective. The Brookings Institution (Ed.), Washington.

El-Geneidy, A.; Levinson, D.; Diab, E.; Boisjoly, G.; Verbich, D.; Loong, C., 2016. The cost of equity: Assessing transit accessibility and social disparity using total travel cost, 2016-09, Transportation research. Part A, Policy and practice Vol.91: 302-316.

El-Geneidy, A.; Levinson, D., 2006. Access to destinations: Development of Accessibility Measures. St. Paul: Minnesota Department of Transportation.

European Commission, n.y.. Sustainable Urban Mobility Plans. Retrieved June 17th from https://ec.europa.eu/transport/themes/urban/urban-mobility/urban-mobility-actions/sustainable-urban_en.

Foth, N.; Manaugh, K.; El-Geneidy, A., 2013. Towards equitable transit: examining transit accessibility and social need in Toronto, Canada 1996-2006, 2013-05, Journal of Transport Geography Vol. 29, 1-10.

Fan, Y.; Guthrie, A.; Levinson, D., 2012. Impact of light-rail implementation on labor market accessibility: A transportation equity perspective, 2012, The Journal of transport and land use Vol. 5 (3): 28-39.

Farrington, J.; Farrington, C., 2005. Rural accessibility, social inclusion and social justice. Towards conecptualisation. 2005, Journal of Transport Geography Vol. 13: 1-12.

Fransen, K.; Neutens, T.; Farber, S.; De Mayer, P.; Deruyter, G.; Witlox, F., 2015. Identifying public transport gabs using time-dependent accessibility levels, 2015-10, Journal of Transport Geography Vol. 48: 176-187.

Geurs, K.; van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions, 2004, Journal of Transport Geography Vol. 12: 127-140.

Gidam, M.; Kalasek, R.; Pühringer, F., 2020. GTFS in Public Transport Accessibility Analysis, AGIT – Journal für Angewandte Geoinformatik Vol. 6: 316-329.

Gössling, S., 2016. Urban transport justice, 2016-07, Journal of Transport Geography Vol. 54: 1-9.

Gsteu, J. G., 2015. Josef-Bohmann-Hof. In: Gsteu, Johann Georg (publ., 2015): Friedrich Achleitners Blick auf Österreichs Architektur nach 1945. Berlin, München, Boston: De Gruyter: 245-249.

Halden, D., 2011. The use and abuse of accessibility measures in UK passenger transport planning, 2011, Research in Transportation Business & Management Vol. 2: 12-19.

Hansen, W., 1959. How accessibility shapes land use, 1959, Journal of the American Institute of Planners Vol. 25 (2): 73-76. Retrieved June 25th 2021 from https://www.tandfonline.com/doi/pdf/10.1080/01944365908978307.

Heidelberg Institute for Geoinformation Technology, University of Heidelberg, n.y.. About us. Retrieved July 2nd2021, from https://heigit.org/.

Heidelberg Institute for Geoinformation Technology, University of Heidelberg, 2021. About us. Retrieved July 1st, 2021, from https://github.com/GIScience/openrouteservice-docs#$pedestrian-speeds .

Huang, H.; Wu, J.; Liu, F.; Wang, Y., 2020. Measuring accessibility based on improved impedance and attractive functions using taxi trajectory data, 2021, Sustainability Vol. 13: 112.

Hu, L.; Fan, Y.; Sun, T., 2017. Spatial or socioeconomic inequality? Job accessibility changes for low- and high-education population in Beijing, China. Cities 66, 23-33.

Jeekel; J.; Martens, K., 2017. Equity in transport: Learning from the policy demains of housing, health care and education, 2017, European Transport Research Review Vol. 9: 53.

Kenyon, S.; Lyongs, G.; Rafferty, J., 2002. Transport and social exclusion: investigating the possibility of promoting inclusion through virtual mobility, 2002, Journal of Transport Geography Vol. 10: 207-219.

Knoflacher, H.; Frey, H.; Ripka, I.; Leth, U., 2016. Auswirkungen der Lobauautobahn auf die Stadt Wien, 2016, Technische Universität Wien. Retrieved August 2nd 2021. https://www.fvv.tuwien.ac.at/fileadmin/mediapool-verkehrsplanung/Bilder/Forschung/Online_Volltext_Publikationen/tu-auswirkungen-lobauautobahn.pdf.

Levinson, D.; Wu, H., 2019. Towards a general theory of access, 2019, The Journal of Transport and Land Use Vol. 13(1): 129-158.

Litman, T., 2003. Measuring transportation: Traffic, mobility and accessibility, 2003, Institute of Transport Engineers Journal Vol. 73(10): 28-32.

Lucas, K.; Philips, I.; Mulley, C.; Ma, L., 2018. Is transport poverty socially or environmentally driven? Comparing the travel behaviours of two low-income populations living in central and peripheral locations in the city, 2018-10, Transportation Research. Part A, Policy and Practice Vol. 116: 622-634.

Lucas, K., 2006. Providing transport for social inclusion within a framework for environmental justice in the UK, 2006, Transportation Research. Part A, Policy and Practice Vol. 40: 801-809.

MA18 - Municipal Department 18, 2020a. Fachkonzept „Mittelpunkte des städtischen Lebens – Polyzentrales Wien“. Retrieved April 23rd from https://www.wien.gv.at/stadtentwicklung/strategien/step/step2025/fachkonzepte/polyzentrales-wien/ueberblick.html.

MA18 - Municipal Department 18, 2020b. Bevölkerung April 2020. Einwohnerdichte. Retrieved August 2nd 2021 from https://www.wien.gv.at/stadtentwicklung/grundlagen/stadtforschung/karten/bevoelkerung.html.

MA18 – Municipal Department 18, 2017. Wohnbevölkerung je Zählgebiet nach Altersgruppen 2017. Retrieved April 5th, 2021 from https://www.wien.gv.at/stadtentwicklung/grundlagen/stadtforschung/karten/pdf/bevoelkerung-altersgruppen-2017.pdf.

MA18 - Municipal Department 18, 2016. Smart City Wien. Framework Strategy. Vienna, 2016. Retrieved June 17th 2021 from https://www.wien.gv.at/english/urbanplanning/.

MA18 - Municipal Department 18, 2015. Urban Mobility Plan Vienna. Vienna, 2015. Retrieved March 17th 2021 from https://www.wien.gv.at/english/urbanplanning/.

MA18 - Municipal Department 18, 2014. Urban Development Plan Vienna STEP2025. Vienna, 2014. Retrieved March 17th 2021 from https://www.wien.gv.at/english/urbanplanning/.

MA18 & ZSI - Municipal Department 18 & Centre for Social Innovation (ZSI), 2013. Sozialräumliche Cluster Wien. Retrieved March 9th 2021 from https://www.wien.gv.at/stadtentwicklung/grundlagen/stadtforschung/karten/pdf/sozialraeumliche-cluster-2012.pdf.

MA21 – Municipal Department 21, 2019. Leitfaden Mobilitätsmaßnahmen im Wohnbau. Übersicht und Planungsempfehlungen für Wohnbauvorhaben in Wien. Retrieved August 3rd, 2021 from https://www.urbaninnovation.at/tools/uploads/Werkstattbericht_Mobilitaetsmassnahmen_im_Wohnbau.pdf .

MA23 - Municipal Department 23, 2021. Zugelassene Kraftfahrzeuge seit 2002- Bezirke Wien. Retrieved August 2nd 2021, from https://www.data.gv.at/katalog/dataset/3e9af1f2-9333-4c1c-978f-9a0c6771fce3.

MA23 - Municipal Department 23, 2020a. Population in the 23 municipal districts by sex since 1869. Retrieved on June 6th 2021 from https://www.data.gv.at/katalog/dataset/091a085f-2652-429f-8dde-c69199440ddf.

MA23 - Municipal Department 23, 2020b. Population projection for 23 municipal districts in Vienna by age groups and sex 2014 to 2034. Retrieved on June 6th 2021 from https://www.data.gv.at/katalog/dataset/7271d091-21aa-402b-b22e-af473374664c .

MA41 – Municipal Department 41, 2021. Orthofoto 2020 Vienna. Retrieved June 12th from https://digitales.wien.gv.at/schnittstellen-geowebservices/.

MA8 & MA9 – Municipal Departments 8 and 9, 2021a. Simmering. Retrieved August 2nd, 2021 from https://www.geschichtewiki.wien.gv.at/Simmering .

MA8 & MA9 – Municipal Departments 8 and 9, 2021b. Liesing. Retrieved August 4th, 2021 from https://www.geschichtewiki.wien.gv.at/Mauer_(Ort).

MA8 & MA9 – Municipal Departments 8 & 9, 2021c. Friedrich-Engels-Platz-Hof. Retrieved August 5th, 2021 from https://www.geschichtewiki.wien.gv.at/Friedrich-Engels-Platz-Hof.

Martens, K., 2017. Transport Justice. New York: London: Taylor and Francis, Routledge 2017.

Martens, K., 2012. Justice in transport as justice in accessibility: applying Walzer's 'Spheres of Justice' to the transport sector, 2012-11, Transportation Vol. 36(6): 1035-1053.

Martens, K.; Golub, A.; Robinson, G., 2012. A justice-theoretic approach to the distribution of transport benefits: Implications for transportation planning practice in the United States, 2012, Transport Research. Part A, Policy and Practice Vol. 46: 684-695.

Matznetter, W., 2002. Social Housing Policy in a Conservative Welfare State: Austria as an Example, 2002, Urban Studies Vol. 39(2): 265-282.

Miller, H., 2005. Place-Based Versus People-Based Accessibility. In: Levinson, D.M. and Krizek, K.J. (Ed.): *Access to Destinations,* Emerald Group Publishing Limited, Bingley. 63-89.

Mullen, C.; Tight, M.; Whiteing, A.; Jopson, A., 2014. Knowing their place on the roads: what would equality mean for walking and cycling?, 2014, Transportation Research. Part A, Policy and Practice Vol. 61: 238-248.

Nazari Adli, S.; Donovan, S., 2018. Right to the city: Applying justice tests to public transport investments, 2018, Transport Policy Vol. 66: 56-65.

Neutens, T.; Schwanen, T.; Witlox, P.; De Maeyer, P., 2010. Equity of urban service delivery: a comparison of different accessibility measures, 2010, Environment and Planning A Vol. 42: 1613-1635.

ÖBB-Personenverkehr AG, 2018. Soll Fahrplan GTFS. Retrieved April 7th, 2021 from https://data.oebb.at/#default/datasetDetail. Original data from 2018, updated 2020.

ÖDVAT – Österreichisches Institut für Verkehrsdateninsfrastruktur, 2021. OGD GIP, released April 2021. Retrieved May 2nd, 2021 from https://www.gip.gv.at/en/index.html.

Owen, A.; Murphy, B., 2020. Access Across America: Transit 2018. Final Report. Minneapolis: Accessibility Observatory, University of Minnesota.

Pirhofer, G.; Stimmer, K., 2007. Pläne für Wien. Theorie und Praxis der Wiener Stadtplanung von 1945 bis 2005. Vienna: Stadtentwicklung Wien, Magistratsabteilung 18.

Prinz, T.; Herbst, S., 2008.: Multikriterielle Modellierung der ÖV-Erreichbarkeit für die Stadt Wien. Vienna, 2008.

Pyrialakou, D.; Gkritza, K., Fricker, J., 2016. Accessibility, mobility and realized travel behavior: Assessing transport disadvantage from a policy perspective, 2016, Journal of Transport Geography Vol. 51: 252-269.

Rawls, J., 1971. A theory of Justice. Harvard University Press.

Sager, T., 2005. Footloose and Forecast-free: Hypermobility and the Planning of Society, 2005-01, European Journal of Spatial Development Vol. 17: 1-23.

Schwanen, T.; Lucas, K.; Akyelken, N.; Cisternas Solsona, D.; Carrasco, J.; Neutens, T., 2015. Rethinking the links between social exclusion and transport disadvantage through the lens of social capital, 2015, Transportation Research. Part A, Policy and practice, Vol. 74: 123-135.

Seawright, J.; Gerring, J., 2008. Case Selection Techniques in Case Study Research: A Menu of Qualitative and Quantitative Options, 2008, Political Research Quarterly Vol. 61 (2).

Shareia, B., 2016.: Qualitative and Quantitative Case Study Research Method on Social Science: Accounting Perspective, 2016, International Journal of Economic and Management Engineering Vol. 10: 3839-3844.

Stanley, J.; David, H.; Stanley, J.; Vella-Brodick, D., 2011. Mobility, social exclusion and well-being: Exploring the links, 2011, Transportation Research. Part A, Policy and practice, Vol. 45: 789-801.

Statistics Vienna, 2020. Vienna in Figures 2020. Retrieved July 2nd, 2021, from https://www.wien.gv.at/statistik/pdf/viennainfigures-2020.pdf .

Statistik Austria, 2021a. Gliederung Österreichs in Gemeinden. Retrieved April 2nd 2021 from https://www.data.gv.at/katalog/dataset/566c99be-b436-365e-af4f-27be6c536358.

Statistik Austria, 2021b. Volkszählung, Registerzählung, Abgestimmte Erwerbsstatistik. Retrieved June 2nd, 2021 from http://www.statistik.at/web_de/statistiken/menschen_und_gesellschaft/bevoelkerung/volkszaehlungen_registerzaehlungen_abgestimmte_erwerbsstatistik/index.html.

Statistik Austria, 2021c. Einwohnerzahl nach Zählsprengel, 1.1.2021. Retrieved August 2nd, 2021 from https://www.statistik.at/web_de/klassifikationen/regionale_gliederungen/statistische_zaehlsprengel/index.html.

Statistik Austria, 2014. Arbeitsstätten nach OENACE (selbstständig/unselbständig); 250m Raster. Provided by SRF, TU Wien on 29th April 2021.

Statistik Austria, 2008. Development of ÖNACE 2008. Retrieved July 2nd 2021 from http://www.statistik.at/web_en/classifications/implementation_of_the_onace2008/development_of_the_onace2008/index.html#index1 .

Suitner, J., 2020. Vienna's planning history: periodizing stable phases of regulating urban development, 1820-2020. Planning Perspectives Vol.ahead-of-print: 1-22.

Vienna City Administration, 2021a. Carsharing. Retrieved August 2nd, 2021 from https://www.wien.gv.at/verkehr/kfz/carsharing/.

Vienna City Administration, 2021b. Stadtplan-Kulturgut. Retrieved August 2nd, 2021 from https://www.wien.gv.at/kulturportal/public/.

Vienna City Administration, 2021c. Wien Kulturgut: Gemeindebauten. Retrieved July 1st, 2021, from https://www.wien.gv.at/kultur/kulturgut/architektur/gemeindebauten.html.

Vienna City Administration, 2020a. EinwohnerInnen-Dichte 2020. Retrieved March 3rd 2021 from https://www.wien.gv.at/stadtentwicklung/grundlagen/stadtforschung/karten/bevoelker-ung.html.

Vienna City Administration, 2020b. Zählbezirksgrenzen. Retrieved March 2nd 2021 from https://www.data.gv.at/katalog/dataset/e4079286-310c-435a-af2d-64604ba9ade5 (02.03.2021).

Vienna City Administration, 2016. Monthly consumer spending in Vienna – a comparison of the consumption survey 2009/10 and 2014/15. Retrieved June 6th 2021 from https://www.wien.gv.at/statistik/wirtschaft/tabellen/konsumerh-wien-vergleich-05-10.html.

Vienna City Administration, 2011. Zählgebietsgrenzen. Retrieved April 7th, 2021 from https://www.data.gv.at/katalog/dataset/0adc90c9-ac6b-47ef-aa83-b7780594720c.

City of Vienna, n.y. Vienna Cycle Network. Retrieved July 18th, 2021 from https://www.wien.gv.at/english/transportation-urbanplanning/cycling/cycle-network.html .

Verlinghieri, E.; Schwanen, T., 2020. Transport and Mobility Justice: Evolving Discussions, 2020-07, Journal of transport geography Vol. 87: 102798.

Walzer, M., 1983. Spheres of Justice. A defense of pluralism and equality. New York, 1983: Basic Books.

Wang, C.; Chen, N., 2015. A GIS-based spatial statistical approach to modeling job accessibility by transportation mode: case study of Columbus, Ohio, 2015, Journal of Transport Geography Vol. 45: 1-11.

Widholm, K., 2021. E-Scooter ausleihen: Die fünf Roller Sharing Systeme in Wien. Retrieved August 2nd, 2021 from https://www.stadt-wien.at/wien/news/e-scooter-sharing-system-in-wien.html.

Wiener Linien, 2021. Public Transport Network. Retrieved August 20th from https://www.data.gv.at/katalog/dataset/36a8b9e9-909e-4605-a7ba-686ee3e1b8bf.

Wiener Linien, 2020. ASTAX wird zu Rufbus. Retrieved August 10th, 2021 from https://blog.wienerlinien.at/astax-wird-zu-rufbus/.

Wiener Linien, 2017. Wiener Linien – Fahrplandaten GTFS Wien. Retrieved April 4th, 2021 from https://www.data.gv.at/katalog/dataset/ab4a73b6-1c2d-42e1-b4d9-049e04889cf0 . Original data from 2017, updated December 2020.

Wiener Linien, n.y. WienMobil Stationen. Retrieved August 2nd, 2021 from https://www.wienerlinien.at/web/wiener-linien/wienmobil-stationen#close

Wien Museum, 2021. The Origins of Vienna. A historical riddle in 41 characters. Retrieved June 29th , 2021 from https://www.wienmuseum.at/en/locations/roemermuseum.

Wien Museum, 2019. Das Rote Wien 1919-1934. Retrieved June 29th, 2021 from https://www.wienmuseum.at/de/ausstellungen/aktuell/ansicht/das-rote-wien-1919-1934.

Wiener Wohnen – Stadt Wien, 2019. Social Housing in Vienna. Retrieved March 12th, 2021 from https://www.wienerwohnen.at/wiener-gemeindebau/municipal-housing-in-vienna.html%22%7D%20--%3E%20%3Cfigure%20class=%22wp-block-embed%22%3E%3Cdiv%20class=%22wp-block-embed__wrapper.

Wiener Wohnen, n.y. Gemeindebaubeschreibungen. Retrieved August 2nd, 2021 from https://www.wienerwohnen.at/wiener-gemeindebau/gemeindebau-beschreibungen.html?gbSearchDistrict=1110&gbSearchStreet=&gbSearchYear=&gbSearchArchitect=&gbSearchFlatCount=&page=1&rows=5&sorting=1,asc,0.

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