Master's thesis

To achieve the academic degree of Master of Science

Calming traffic in Berlin's center – assessing the conversion potential of traffic area with open-source data

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Submitted to the Department of Geography, Humboldt University of Berlin, 08.11.2024

Acknowledgement

I am deeply grateful to everyone who supported me in the journey of completing this Master's thesis.

First, I want to express my sincere thanks to my supervisors, Prof. Dagmar Haase and Dr. Manuel Wolff, for their impressive expertise, encouraging words, kindness, and dedicated support. Their guidance and insight were instrumental in helping me navigate both the challenges and discoveries of the research process.

Special thanks go to the team behind the OpenStreetMap Parkraum Projekt, without which I could not have pursued my absolute dream topic. This remarkable project, which creates and continuously updates datasets on on-street parking spaces, made this thesis possible in the first place. In particular, I am immensely grateful to Alex Seidel, whose generosity and openness in answering my countless questions about the datasets were invaluable. I truly could not have written this study without him.

I am also very thankful to the staff members at the Berlin Senate Departments for Mobility, Transport, Climate Protection and the Environment, and Urban Development, Building, and Housing, as well as the Statistical Office for Berlin-Brandenburg. Their willingness to answer my questions and provide data with such friendliness significantly enriched my research.

Finally, to my friends and family who stood by me every step of the way: their constant emotional support was essential in carrying me through the challenges of this work. They lifted my spirits when I felt lost, offered perspectives that helped me recognize both the strengths in my work and my own capabilities, cooked meals and made tea for me (symbolic of the many ways they showed care), celebrated my achievements, and visited when I needed it most. For always being there to listen and encourage, I am profoundly grateful. A special thanks for their active support and lots of love goes to Franzi, Kolja, Lauri, Lisi, Maeve, Marie, Melanie, Wolle, and my wonderful flatmates.

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Abstract

Urban areas offer many benefits to their residents, but they also pose significant health risks, particularly due to motorized traffic. Motorized traffic contributes to noise pollution, poor air quality, and increased CO_2 emissions, among other health-threatening factors. To mitigate these effects, many cities have been converting traffic areas for alternative uses. However, empirical data on traffic areas remains limited, complicating assessments of traffic-reducing measures. This study addresses this gap by estimating the conversion potential of traffic areas, intended for motorized traffic, in Berlin's city center, including the objectives to (i) calculate maximum and moderate area potentials, (ii) define conversion options, and (iii) identify priority planning areas for conversion measures. To achieve this, I used open-source data from OpenStreetMap to create geospatial traffic area datasets. I estimated a maximum area potential based on total traffic space, while a moderate area potential retained some traffic areas for essential vehicles. Conversion options were defined based on these area potentials, and priority planning areas were identified based on their traffic area size and green space provision. My results indicate that approximately 14% of the total area within Berlin's center is currently dedicated to motorized traffic infrastructure, representing a maximum area potential for conversion. If some motorized vehicles remain in Berlin's center, around 10% of the total area could potentially be converted, indicating a moderate area potential. In addition, the results introduce three options for convertible area sizes and their potential distribution in Berlin's center. Priority areas for conversion include the planning areas Julius-Leber-Brücke, Stülerstraße, Droysenstraße, and Hausburgviertel. The study provides the first comprehensive estimate of traffic space in Berlin's center, offers initial insights into potential areas and area sizes for conversions as well as area prioritization based on an environmental justice indicator. Consequently, the findings offer urban planners and policymakers a traffic area size-driven foundation for evaluating traffic-calming and area conversion strategies, ultimately fostering both environmental sustainability and urban equity.

Keywords: Motorized traffic, Traffic calming, Traffic area conversion, Geospatial data, OpenStreetMap, Berlin, Berlin's center, Sustainable urban development

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1 Introduction

Cities worldwide are experiencing significant growth in both population and spatial extent (UN, 2018). Currently, over half of the global population lives in urban areas, with projections indicating this proportion will increase to two-thirds by 2050 (UN, 2018). This urban expansion is driven inter alia by economic opportunities, cultural offerings, and improved access to healthcare and education – benefits often scarce in rural areas (Adli et al., 2017; Gruebner et al., 2017). At the same time, however, cities present their inhabitants with various challenges, some of which even threaten resident's health. These include, for example, elevated air and noise pollution (Kampa & Castanas, 2008; Wróblewska & Jeong, 2021); high urban temperatures (urban heat island) increasing the risk of health-related morbidity and mortality (Oke, 1980; Liu et al., 2023); or limited space for recreation, physical activity or nature experiences by urban residents (Adli & Schöndorf, 2020).

One of the main contributors to the above-mentioned and additional health-threatening challenges in cities is motorized road traffic. One risk of motorized traffic is the continued prevalence of road traffic accidents, representing a significant global health challenge in mortality and morbidity (WHO, 2023). In addition, motorized traffic is a primary driver of air and noise pollution (HEI, 2010; EEA, 2020) and a main source of European greenhouse gas emissions (EEA, 2019). As motorized traffic mainly uses sealed surfaces, it further indirectly contributes to high urban temperatures (Petralli et al., 2014) by absorbing solar radiation and preventing the cooling effect of evapotranspiration (Liu et al., 2023). Driving and parking motorized vehicles further take up much more space than other modes of transportation, such as cycling, walking or public transportation (Agentur für clevere Städte, 2014; Nello-Deakin, 2019; VTPI, 2021). Unlike active forms of mobility, such as walking and cycling, using motorized vehicles does not promote health through physical activity (Mackett & Brown, 2011). These adverse health effects attributable to motorized traffic indicate that traffic calming and the conversion of traffic areas can positively affect urban health (Mueller et al., 2020).

One land use that repeatedly appears in urban planning because of its health-promoting effects is urban green spaces (UGSs) (Gehl, 2016; McCay et al., 2016; Pisello et al., 2024). UGSs inter alia include street trees, greenery on the roadsides or between or beside railways, (pocket) parks, urban forests, playgrounds, gardens, and green roofs (Becker et al., 2014; Ward Thompson & Silverinha de Oliveira, 2016). UGSs provide many positive effects on the health of city dwellers and the urban environment, as various studies have shown. For example, UGSs can decrease air temperature (Shanahan et al., 2015; Liu et al., 2023), thereby reducing heat-related morbidity and mortality (Gabriel & Endlicher, 2011) and enhancing outdoor thermal comfort, which promotes physical activity (Pandey, 2023; Edeigba et al., 2024). Additionally, UGSs can improve air quality (Wróblewska & Jeong, 2021; Han et al., 2024) and increase biodiversity (FitzGibbon et al., 2007; Rupprecht et al., 2015), which can positively influence resident's mental health (Ratcliffe et al., 2013; Lorenzo et al., 2016). Other health-promoting effects of green spaces are the strengthening of social cohesion (Peters et al., 2010; Veen et al., 2016), the opportunity for recreation (Elmqvist et al., 2015; Lee et al., 2015), the stimulation of physical activity (Sugiyama et al., 2010), and the possibility of creating a pedestrian and cyclist-friendly infrastructure (Schoeppe & Braubach, 2007; WHO, 2018). However, cities often lack sufficient UGSs (Nieuwenhuijsen & Khreis, 2016). The Urban Atlas (of 2018), for example, shows that capital cities in Europe have an overall low proportion of urban green spaces (EEA, 2022).

To improve residents' quality of life and ecological resilience, cities such as Barcelona (Spain), Oslo (Norway) and Paris (France) promote an ecological shift in transportation and convert traffic areas (Rueda, 2019; Doheim et al., 2020; Tennøy & Hagen, 2020). Barcelona's superblock concept entails that the maximum speed within the blocks is reduced to 10-20 km/h, which encourages the use of non-motorized road users (Rueda, 2019). In Oslo, street parking spaces have been removed, sidewalks have been extended, and pedestrian zones with benches have been created. Additionally, parking spaces and paths for bicycles were created and car parking spaces for people with disabilities and delivery traffic (Tennøy & Hagen, 2020). Similarly, in Paris, car parking spaces in the seven main squares have been reduced to make room for pedestrians (Doheim et al., 2020). Green spaces with trees, lawns, and flower beds were created, as well as similar measures for cyclists as in Oslo (Doheim et al., 2020). Further, policies are also implemented to foster an ecological shift in transportation. For instance, Berlin (Germany) passed the first mobility law in 2018 that prioritizes public transportation, walking, and cycling to improve the quality of life in the city's neighborhoods (SenMVKU, n.d.). That indicates that Berlin's policy is promoting the calming of motorized traffic, making Berlin a suitable area for traffic area conversion suggestions.

Despite the advantages of calming traffic and converting traffic areas, their implementation presents several challenges. First, one key challenge is the lack of comprehensive traffic area data (Gössling et al., 2016). In Berlin's city center, data on areas intended for motorized traffic either refer to the share of road users within all traffic areas (Agentur für clevere Städte, 2014), or include areas beyond those specifically designated for motorized traffic (SenStadt, 2021). However, quantitative data on areas exclusively intended for motorized traffic is missing. Having access to the spatial data of these areas would allow for effective identification of conversion opportunities and the quantification of potential traffic area conversions. Second, the examples of Oslo and Paris showed many possible traffic calming measures, resulting in different convertible traffic area sizes (depending on policy strategies). Finding a suitable alternative use for these areas is challenging, as it, for example, depends on the location and the population needs. In line with that, measures for traffic calming and space conversion in a neighborhood in Berlin ("Badstraße") are planned based on surveys and space availability (Bezirksamt Mitte Berlin, 2020). Third, traffic area conversions to enhance the quality of life may increase the attractivity of already more privileged (e.g., high income, low environmental pollution, good green space provision) urban areas. Therefore, urban planners should not increase environmental injustice and may prioritize more burdened areas for traffic area conversions. Similarly, the urban planning strategy for Berlin in 2030 defines priority areas for development plans and projects (Senatskanzlei Berlin, 2022). These priority areas have the greatest potential for beneficial urban development and simultaneously experience pronounced social and economic disadvantages (ibid.).

The resulting research questions of this study are:

RQ1: What is the area potential of the traffic areas in Berlin's center?

RQ2: How could these traffic areas be converted?

RQ3: Which planning areas in Berlin's center may be prioritized for the conversion of the traffic areas?

To address these research questions, this paper splits into three research objectives. Objective A is to calculate the maximum and moderate traffic area conversion potential in Berlin's center, based on the absolute traffic area size, to address RQ1. If motorized traffic in Berlin's center were to be reduced, these area calculations could offer a starting point for quantifying traffic area conversion measures. The maximum area potential indicates the total traffic area in Berlin's center (i.e., the study area). In contrast, the moderate area potential is smaller, as it accounts for some car traffic in the study area. Objective B aims to define three options for convertible traffic areas based on the previously obtained potentials to address RQ2. As calming traffic and traffic area conversions can offer advantages for the inhabitant's health and the urban environment, the options aim to show what size-related measures can look like. Lastly, objective C is to compare the traffic areas of the three previously defined options to the green space provision per planning areas of Berlin's center. The green space provision is one of Berlin's environmental justice indicators (SenMVKU, 2022a). The comparison aims to identify the planning areas in the study area that I propose to prioritize for traffic area conversion measures (RQ3). On the one hand, they may have the greatest potential for land conversion; on the other hand, they are most affected by a poor supply of green space. The aim of this paper is to assess the potential for conversion of traffic area in the event of traffic calming in the center of Berlin.

2 Study Area and Definition of Traffic Areas

The study area is located in the center of Berlin (Germany). Germany's capital, Berlin, is the largest and most populous city in Germany, as it inhabits 3.878 million people (as of 2023) (AfS, 2024) in an area of 89,112 ha (as of 2022) (AfS, 2023b). As the city continues to grow, its population is projected to reach 3.96 million by 2040 (SenStadt, n.d.b). Today, 71% of Berlin's surface area is covered by buildings and traffic areas, whereas 29.4% are vegetation and water bodies (AfS, 2023b).

I restricted the study area to the city's center, which is framed by Berlin's ring-shaped railway ('Ringbahn') and I refer to it as 'Berlin's center' in this paper. This area represents Berlin's 'low-emission zone' and the innermost fare zone of the transport association. At 8,746 ha, the study area covers around 9.8% of Berlin's total area (see script 1). The population density of the study area is around three times that of the whole city, at 129 inhabitants per hectare (as of 2021) (SenStadt, n.d.a).

The study area was chosen for this study because it is most burdened by environmental injustice compared to all of Berlin, as shown in the latest Environmental Atlas of Berlin of 2022 (SenStadt, n.d.c). Other reasons for selecting the study area include the strong voting trend for the Green Party in 2021 in the study area (AfS, 2023a), which indicates broad public approval of traffic calming measures. Additional reasons are the relatively low prevalence of motorized private transport especially in Berlin's center (Gerike et al., 2020), and the presence of a well-established public transport system (Business Location Center, n.d.).

To analyze the traffic areas in this study, areas are divided into three traffic area types intended for motorized traffic:

A. Off-street parking spaces,
B. On-street parking spaces and
C. The Roadway area.

Off-street parking spaces relate to the collective parking spaces for multiple cars at street level. On-street parking spaces include areas where cars are parked either entirely on the street, half on the street, or on extra parking lanes alongside the street. The roadway area describes the area that is effectively used for driving, usually bounded by a lane marker or the area from curb to curb minus the on-street parking spaces.

3 Data and Methods

3.1 Data Acquisition

My analysis is based on four datasets I created with open-source data: 1. Off-street parking space dataset, 2. On-street parking space dataset, 3. Roadway area dataset, and 4. Green space provision dataset. The first three datasets are the three types of traffic areas that I created using OpenStreetMap (OSM) data and data of an OSM-parking-space-project (OpenStreetMap contributors, n.d.a) (see Table 1). The fourth dataset represents one of the key environmental justice indicators I obtained from Berlin's Environmental Atlas of 2021/2022 (SenMVKU, 2022a) (see Table 1). Figure 1 illustrates the workflow of the data acquisition, data processing, and analysis. The following subsections describe the data sources and their acquisition according to the four created datasets.

Table 1: Data sources for the creation of the four datasets.

Data Sources	Created Datasets
OpenStreetMap (OSM)	Off-street parking spaces
OSM-parking-space-project	On-street parking spaces
OpenStreetMap (OSM) & OSM-parking-space-project	Roadway area
SenMVKU (Mobilität, Verkehr, Klimaschutz und Umwelt), Umweltatlas Berlin	Green space provision

3.1.1 Data Acquisition – Off-Street Parking Spaces

To generate the off-street parking space dataset, I used OpenStreetMap (OSM) data. OSM is a community-based mapping service that aims to create a worldwide database of geospatial data (OpenStreetMap Wiki contributors, 2024a). The increasing number of mapped features in OSM (OpenStreetMap Wiki contributors, 2024c) makes the data more accurate over time. Further information about OSM can be found in Appendix 1.

The off-street parking spaces, as I defined them, were downloaded from OSM with the object category (key) ‘amenity:parking’ and its value ‘surface’. These are polygons of “the dedicated areas for parking consisting of one level of parking on the ground” (OpenStreetMap Wiki contributors, 2024d). I imported them with the 'QuickOSM' (Version 1.17.1) plugin in QGIS (Version 3.36.1), which downloads the data from the Overpass server (3Liz, 2022).

3.1.2 Data Acquisition – On-Street Parking Spaces

I generated the on-street parking spaces using the multi-line dataset ‘parking segments’ by the OSM-parking-space-project (provided by OpenStreetMap contributors, n.d.b). The project is part of the voluntary work of OpenStreetMap’s working group called ‘traffic turnaround’ (originally: Arbeitsgruppe Verkehrswende). They developed three on-street parking space datasets of Berlin because “data on roadside parking is not yet part [of OSM’s] ‘standard information’ and only rudimentarily recorded in many places” (Seidel & OpenStreetMap-Contributors, 2021). The dataset ‘parking segments’ contains the smallest part of a street with parking information on each side of the road where parking is or is not allowed (gislars et al., 2023).

Like the OSM data, the working group's datasets are continuously updated and can be downloaded from their website. During my data analysis, the most recent ‘parking segments’ dataset was from October 14, 2023. At that time, it was the only available dataset on on-street parking in Berlin’s center. Further information on the ‘parking segments’ data set can be found in Appendix 1. Since some parking segments are missing information, e.g. whether parking is permitted and if so, in what length and width, the data was supplemented as described in the Data processing section (Chapter 3.2.1).

3.1.3 Data Acquisition – Roadway Area

For the roadways, I used the open source OpenStreetMap (OSM) data with the object category (key) 'highway' and the values ‘primary’, ‘secondary’, ‘tertiary’, ‘unclassified’, ‘residential’, ‘living street’, ‘pedestrian’ to get the different road types (OpenStreetMap Wiki contributors, 2024b). I downloaded the multi-line datasets of each road type using the ‘QuickOSM’ (Version 1.17.1) plugin in QGIS (Version 3.36.1). Other road types either do not exist in the study area or are not considered due to low occurrence.

As the OSM multi-line datasets contain little information about the width, I included the width information from the ‘parking segments’ dataset of the OSM-parking-space-project. The OSM-parking-space-project working group has various width values mapped and, if not, implemented standardized road widths in their parking segments dataset. The standardized default values for road widths depending on their road type are as follows: 17 m for primary roads; 15 m for secondary roads; 13 m for tertiary roads; 11 m for all side roads, such as residential, living street or pedestrian roads (provided by Seidel, 2024). However, single lanes account for fewer widths, which were not considered for the sake of simplicity. Additionally, since, some parking segments are missing information, as described above, missing values had to be added here as well (see Chapter 3.2.2).

3.1.4 Data Acquisition – Green Space Provision

To assess the possible reason for prioritizing planning areas for a traffic area conversion, I used one of the environmental justice maps – ‘green space provision’ (provided by SenMVKU, 2022b). The green space provision map is one of the five core indicators that show environmental (in)justice in Berlin: 1. noise pollution, 2. air pollution, 3. green space provision, 4. bioclimate/thermal ventilation, 5. social disadvantage/status index, lastly updated in 2021/2022 (SenMVKU, 2022a). The green space provision is displayed in three categories: ‘very good/good’, ‘medium’ and ‘poor/very poor’, i.e., ‘not supplied’ and aggregated to the planning areas (ibid.). I chose this indicator inter alia because urban green spaces can contribute to a healthier, equitable, and sustainable urban environment (Lee et al., 2015) and because the Berlin strategy for 2030 prioritizes greening in areas with existing green deficits (Senatskanzlei Berlin, 2022). I downloaded the Web Feature Service (WFS) of the 'green space provision' map from Berlin's geoportal 'FIS Broker' into QGIS (Version 3.36.1) to analyze and visualize the map information. The planning areas of Berlin are the lowest level of the 'lifeworld-orientated rooms’ (originally: lebensweltlich orientierte Räume (LOR)). LOR are the “spatial basis for planning, forecasting, and monitoring demographic and social developments in Berlin” (SenStadt, n.d.c).

3.2 Data Processing

All data is georeferenced in the Coordinate Reference System ETRS89 / UTM zone 33N (EPSG: 25833), which covers the area where Berlin is located. All data processing was carried out in PostgreSQL (Version 13) using pgAdmin 4 (Version 6.1) and is made available on the GitHub repository [https://github.com/AnnaMengden/MA].

To clip all data to the spatial extent of the study area, I created a layer that includes the planning areas within the study area (provided by AfS, 2019). Since the planning area's borders do not necessarily end at the boundary of my study area, some needed to be dissected. The decision of which parts of the planning areas are part of the study area was performed manually, as described in Appendix 2 and shown in script 1. The resulting planning area dataset consists of 145 planning areas.

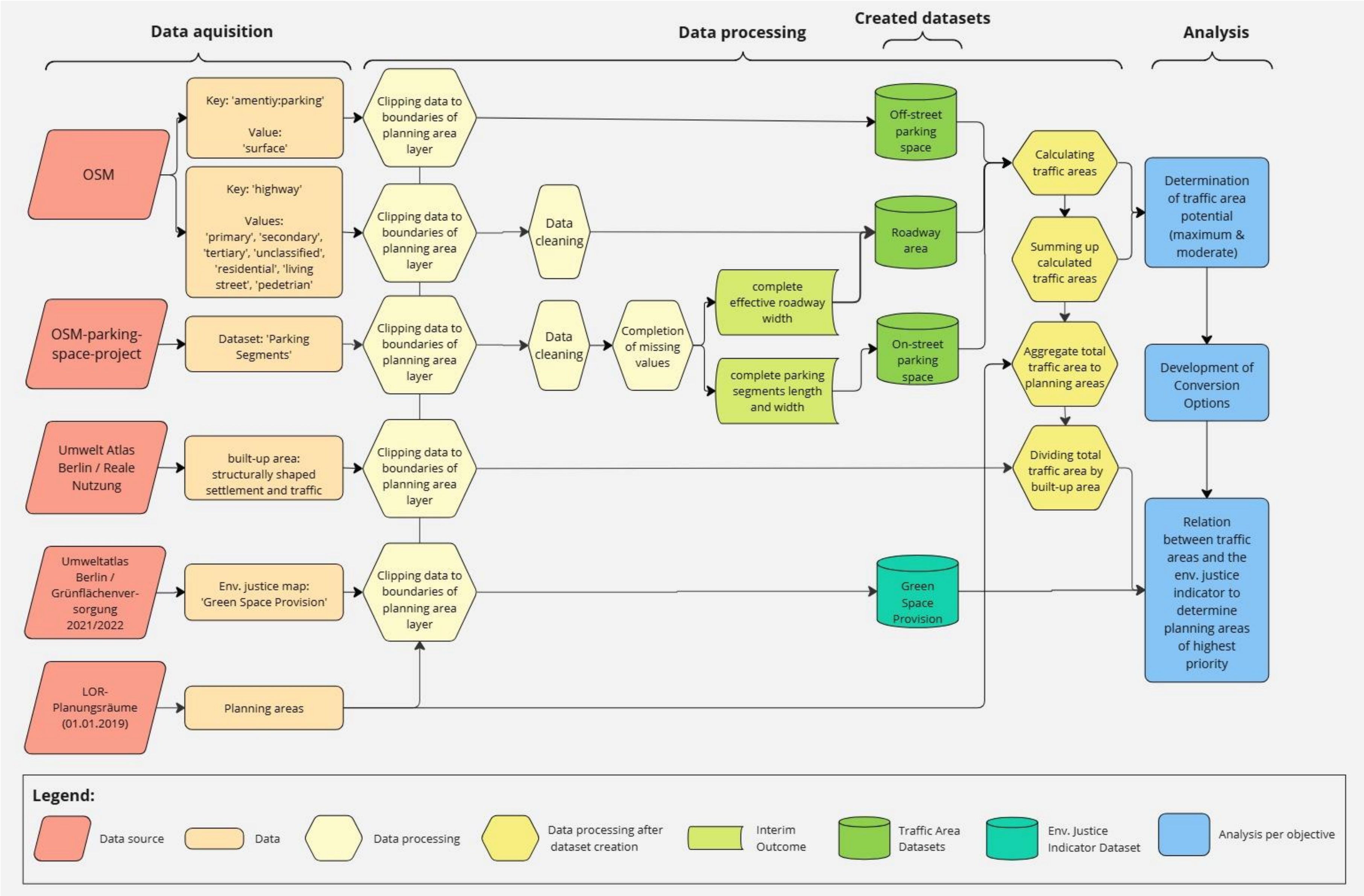

Figure 1: Workflow of data acquisition, processing, and analysis.

To assess the maximum and the moderate area potential (RQ1), I calculated the traffic area of each traffic area type and summed them up. The traffic areas are calculated differently for each traffic area type. The area of the off-street parking spaces is assessed by calculating the polygon's geometries (see script 2). Their spatial distribution in the study area can be seen in Figure 4. Since calculating the areas of the on-street parking space and the roadway is more complex, their area calculation approaches can be found in Chapters 3.2.1 and 3.2.2.

To relate the traffic areas to the green space provision per planning area (RQ3), I first aggregated the traffic areas to the planning areas (provided by AfS, 2019) (see script 6). Second, I divided the total traffic area by the built-up area of the respective planning areas (see script 6). The ratio to the built-up area provides an insight into how intensively the traffic infrastructure is used in the context of the built-up areas of a planning area. This study's 'Built-up area' is the structurally shaped settlement and traffic area, without settlement-free areas such as parks or cemeteries, as defined by IÖR (n.d.). Information on land use was derived from Berlin's land-use map and downloaded via Berlin's geodata portal 'FIS-Broker' (provided by SenStadt, 2022a).

3.2.1 Data Processing – On-street Parking Spaces

To assess the parking area of the on-street parking spaces, I calculated the sum of the product of the length and width of each on-street parking segment from the 'parking segments' dataset. However, as 27.5% of the OSM-parking-space-project dataset's parking segments are classified as 'data missing' or 'not processed yet', some width and length values must be implemented (see script 3). Before completing these values, I corrected some 'not processed yet' segments, as they are mapped twice. The data correction can be found in Appendix 2.1 and script 3. After that, in total 12.4% of the segments are missing width and length values. To estimate the missing values, I developed a probability approach, as exemplified in Figure 3. Thus, I calculated the percentage of parking space per road type (called 'highway' in OSM) because I assume that the frequency with which parking can occur on a particular road type is

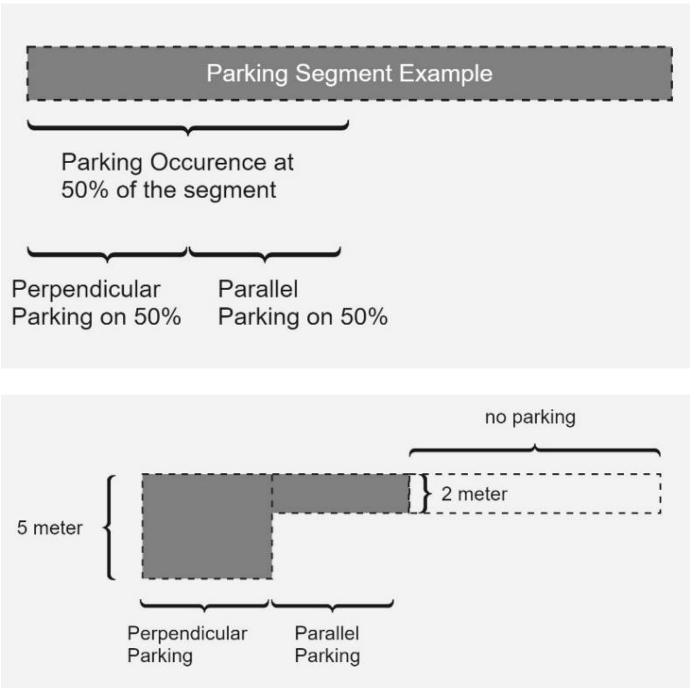

Figure 2: Exemplary illustration of how parking and parking orientation were determined using a probability approach.

similar within that type. I then used these percentages to estimate the likely parking lengths of each segment. For the missing parking width values, I first determined the probabilities of the parking orientations (parallel, diagonal, perpendicular) for each road type for the same reason as just mentioned. Second, I multiplied the standard widths (2 m for parallel, 4.5 m for diagonal, and 5 m for perpendicular (Seidel & OpenStreetMap-Contributors, 2021)) by the calculated parking orientation probabilities to obtain the most likely parking width. All calculations can be found in script 3. The parking segments that can (partly probably) be used for parking according to my dataset are shown in Figure 5. For the illustration, I have buffered the parking segment lines according to their (partly estimated) width.

3.2.2 Data processing – Roadways

The roadway dataset consists of both, the OSM 'highway' multi-line data and the effective roadway width of the 'parking segments' dataset of the OSM-parking-space-project. I assigned the effective road width from the 'parking segments' dataset to the matching road line by their OSM ID. When no parking segment matches a road segment, e.g., because of a crossing, the width of the neighbor geometry was assigned. Additional corrections can be found in the Appendix 2.2. Since values are missing in the 'parking segments' dataset, I also completed the missing effective widths. The approach for that is similar to completing the parking width from Chapter 3.2.1. The percentage of parallel, diagonal, or perpendicular parking was calculated with the respective on-street parking space width (2m, 4.5m, or 5m) for each road type and subtracted from the road width to obtain the effective roadway width.

To calculate the total roadway area, I created a coherent polygon dataset without overlaps. To do so, I united the road segments per road type and buffered them according to their effective roadway width. Afterward, I merged the road polygons hierarchically according to the respective road type. This means that where a hierarchically higher road type overlaps with a hierarchically lower road type, the area is assigned to the 'higher' road type. The hierarchy of the road types is: 1. Primary, 2. Secondary, 3. Tertiary, 4. Unclassified, 5. Residential, 6. Living Street, 7. Pedestrian. Figure 3 shows an example of which roadway area is cut in favor of which roadway area of the first three road types. The merged overlap-free polygon dataset of the roadway area can be seen in Figure 6. Script 4 shows the data processing of the roadway dataset.

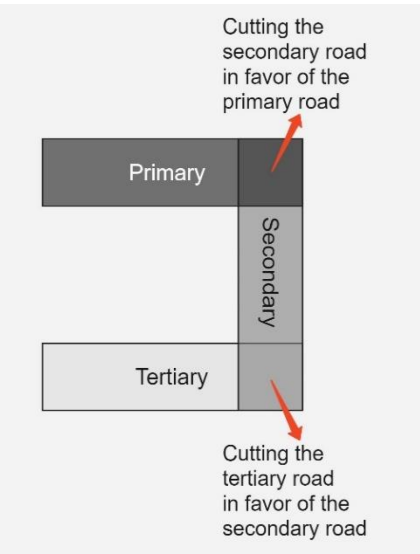

Figure 3: Exemplary illustration of how overlapping road types were addressed.

3.3 Maps of the three Traffic Area Datasets

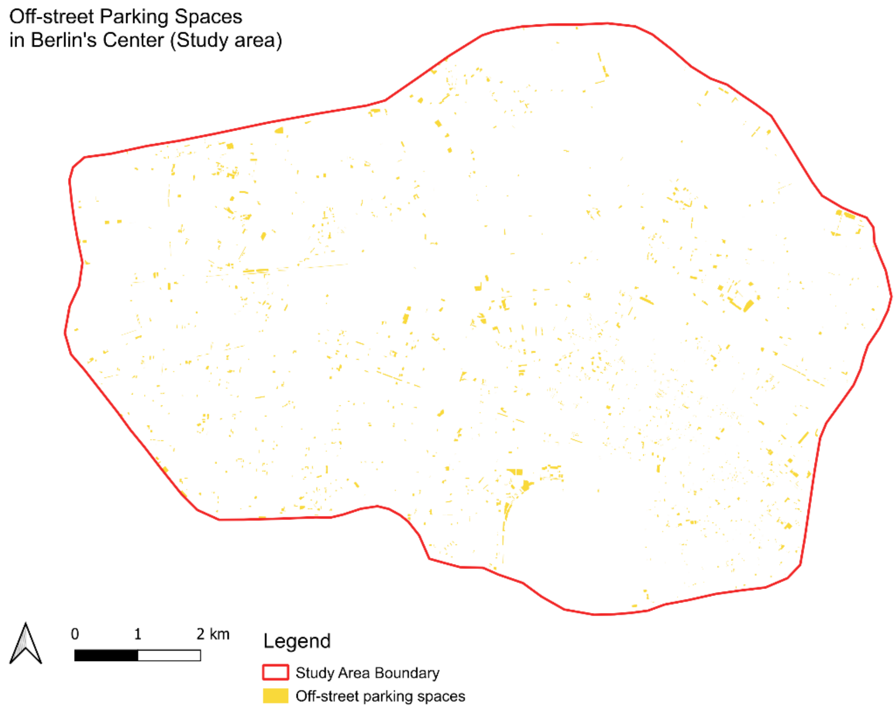

*Figure 4: **Off-street parking spaces in the study area.** Own visualization based on data from: OpenStreetMap (OSM).*

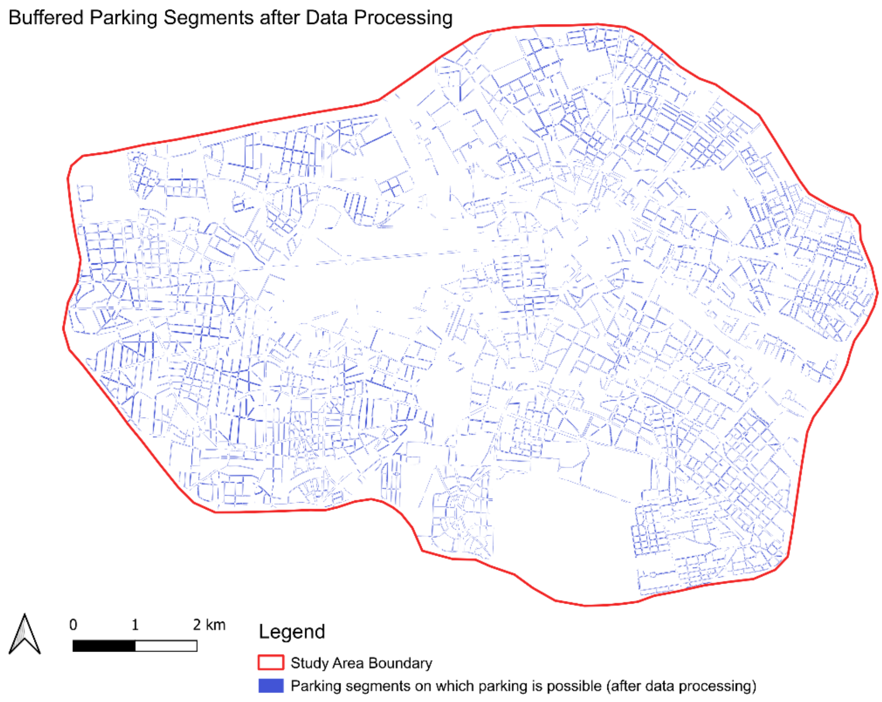

*Figure 5: **Buffered parking segments on which parking occurs, after data processing, in the study area.** Own visualization based on dataset "parking segments" provided by OpenStreetMap contributors (n.d.b).*

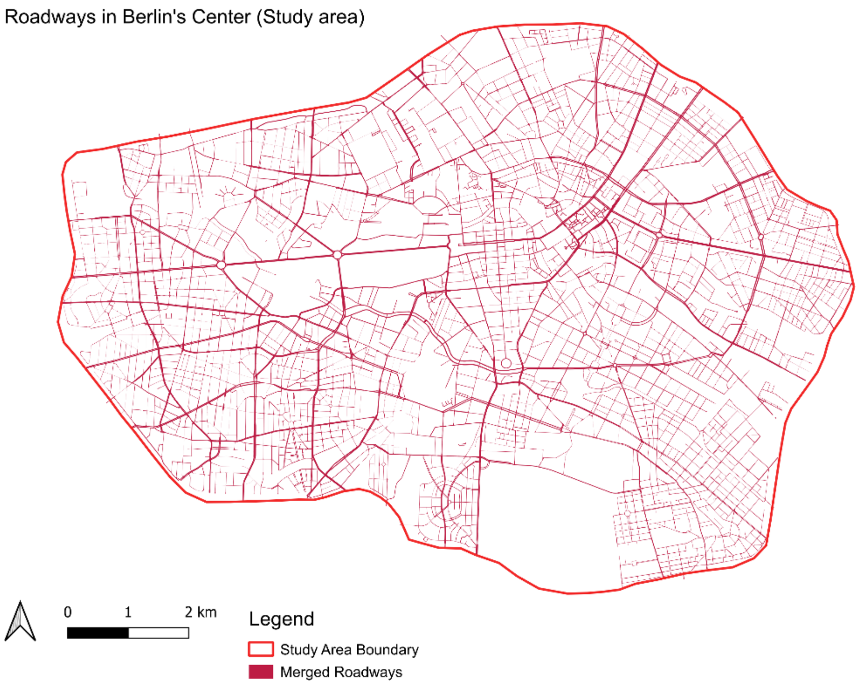

*Figure 6: **Effective roadway area in the study area.** Own visualization based on data sources: OpenStreetMap (OSM) and dataset "parking segments" provided by OpenStreetMap contributors (n.d.b).*

3.4 Analysis

3.4.1 Assessing the Traffic Area Potential

To determine the area potential of the traffic areas (objective A), I opted for two variants: The maximum area potential, in which traffic is calmed to the maximum (no motorized traffic), and the moderate area potential, in which traffic is moderately calmed (some motorized traffic). These two variants are the 'maximum area potential' and the 'moderate area potential'. The maximum area potential in this paper is the sum of all three defined traffic areas – off-street and on-street parking spaces and the roadway area. Therefore, it estimates a size-based maximum conversion potential if Berlin's center were completely traffic-calmed.

In the moderate area potential, some traffic areas remain for motorized traffic. Hence, the moderate area potential results from subtracting an area where motorized traffic is 'permitted' from the total traffic area (maximum area potential). For the sake of simplicity, I solely focused on motorized vehicles 'permitted' to park in on-street parking spaces. The other traffic area types (off-street parking spaces and the roadway area) have no specific motorized private vehicle 'permission'. Instead, the moderate area potentials of these traffic area types are calculated by subtracting the established percentage of the on-street parking spaces that remain as such from their respective total traffic area.

The decision on on-street parking space exceptions was based primarily on the draft law of an initiative to calm traffic in Berlin's center (Initiative Volksentscheid Berlin Autofrei, 2021). It resulted in on-street parking spaces for the following vehicles:

1. Car-sharing cars,
2. Taxis,
3. Cars for people with restricted mobility.

Appendix 3.1 provides a detailed explanation and justification for on-street parking space requirements for the selected vehicles.

The estimate of the number of car-sharing vehicles and taxis is based on the current stock of these vehicles in Berlin. This is because it is difficult to estimate the demand for these vehicles. For the third 'permitted' vehicle, I assumed one car per person with restricted mobility based on information from a 2018 population survey in Berlin (Gerike et al., 2020). In total, that results in 68,421 vehicles ‘permitted’ to park on-street. The assumptions I made to estimate the number of the respective cars can be found in Appendix 3.2.

To calculate the area of the on-street parking spaces required by the ‘permitted’ vehicles, I first calculated the area of a single on-street parking space. I used the length and width per parking space that the OSM-parking-space-project applied (Seidel & OpenStreetMap-Contributors, 2021). The parking space sizes depend on the parking orientation (parallel, diagonal, perpendicular) (Seidel & OpenStreetMap-Contributors, 2021). However, for the sake of simplicity, I calculated a weighted average size per parking space of 11.81m² (see Appendix 3.3). Second, I multiplied the average parking space size by the estimated 68,421 vehicles. The result is an area of 80.8 hectares that remains as on-street parking spaces in the moderate area potential (see Appendix 3.3).

3.4.2 Options for Area Available for Conversion

3.4.2.1 Defining the Options

Objective B is to define different Options for convertible traffic areas based on the calculated maximum and moderate area potentials of RQ1, Objective A. Thus, I defined three conversion options with different traffic area sizes.

Option 1 entails converting the maximum area potential of all three traffic area types—off-street and on-street parking spaces and the effective roadway area (see Table 2). Since no area is intended for motorized traffic, the option is called “Traffic-free”. This option opens up the possibility of eliminating the adverse effects that motorized traffic has on the population and the environment.

In its place, areas can be created that are beneficial to people's health and less harmful to the environment.

Option 2 indicates the conversion of the moderate and the maximum area potential, depending on the type of traffic area. The on-street parking spaces and the roadway area are converted moderately (moderate area potential) (see Table 2). That means that parts of those traffic area types remain as such. On the other hand, the off-street parking spaces are converted entirely (maximal area potential) (see Table 2). Thus, Option 2 is “Traffic-calmed with open spaces”. Option 2, therefore, allows for continuing traffic, which may be crucial. At the same time, traffic areas are reduced, which can facilitate the creation of more health-promoting areas. Additionally, as the entire area of the off-street parking spaces is available for conversion, potentially large open spaces can be created to benefit city dwellers' health.

Option 3 means converting the moderate area potential of all three types of traffic areas (see Table 2). In this approach, parts of all traffic area types remain as traffic areas, while the rest can be converted. Because of that, Option 3 is the “Traffic-calmed” Option. This Option allows the existing traffic area structure to be preserved and enables certain sections to be converted, e.g., into areas that benefit both the environment and the city's population.

Table 2: The three conversion options and the convertible area based on the maximum (max.) and moderate (mod.) area potential.

Option (1) “Traffic-free”	Option (2) “Traffic-calmed & open spaces”	Option (3) “Traffic-calmed”
Max. Off-street parking spaces	Max. Off-street parking spaces	Mod. Off-street Parking Spaces
Max. On-street parking spaces	Mod. On-street Parking Spaces	Mod. On-street Parking Spaces
Max. Roadway area	Mod. Roadway area	Mod. Roadway area

3.4.2.2 Spatially Visualizing the (Non)Convertible Area per Option

Further, I created maps using QGIS (Version 3.36.1) to visualize each option’s extent of the convertible and nonconvertible traffic area (see Figures 8-10). For better recognizability, I chose an extract of the study area, representing a neighborhood section. The extract is located within the planning area “Kaiserin-Augusta-Allee” (district Charlottenburg). This section was chosen because of its comparatively large amount of traffic area of each traffic area type.

My data and analyses do not allow me to make any statements about which traffic areas should remain as such and which should be converted. Therefore, I have chosen different approaches for each type of traffic area to decide which traffic areas are nonconvertible and which are convertible: First, the largest off-street parking spaces remain as such. This way, as many off-street parking spaces as possible can be converted, resulting in the broadest possible distribution of convertible spaces. Second, on-street parking spaces that remain as such are selected randomly, allowing for the broadest possible scattering of convertible on-street parking spaces. Third, the non-convertible roadway area is in the middle of the roadway. This means that the roadway network is retained while both sides of the roadway are convertible.

3.4.3 Determine Areas to be Prioritized for Conversion

The third objective, C, is to relate A) the total traffic area values (relative to the built-up area) and B) the environmental justice indicator, 'green space provision', for all three Options across all planning areas of the study area. To facilitate the visualization of the relationship, I created jitter plots using R (Version 4.4.0) (see script 5). Unlike a scatter plot, this approach allows for better identification of individual points – i.e., planning areas – within each category, as the points are less likely to overlap. By plotting the relative traffic area values against green space provision categories, planning areas with high traffic area values and poor green space provision can be identified. These planning areas could then be prioritized due to their high potential for traffic area conversion and simultaneous deficit in green spaces.

4 Results

4.1 Results 1 – Area Potential

The traffic area was quantified for two variants, i.e., the maximum and moderate area potential (see Table 3). The 'maximum area potential' is the sum of all three traffic area types, resulting in 1,213.16 ha. The largest traffic area is the roadway area, which has 799 ha, followed by 279.48 ha of on-street parking spaces and 134.68 ha of off-street parking spaces. The 'moderate area potential' covers 861.59 ha in total. That results from the sum of the on-street parking spaces subtracted by 80.8 ha, in which parking is 'permitted' (see Chapter 3.4.1) and 71% of all off-street parking spaces and the total roadway area, respectively. This is because 80.8 ha of the maximum area potential of the on-street parking spaces is 29%, which is why 29% of the off-street parking spaces and the roadway area remain as such and 71% of these are their respective moderate area potential. Therefore, the largest share of the traffic area accounts for the roadway area with 567.29 ha, followed by 198.58 ha for on-street parking spaces, followed by 96.62 ha for off-street parking spaces.

Table 3: Results 1. The size-based maximum and moderate conversion potential of Berlin's center's three traffic area types.

Traffic area type	Maximum Area Potential	Moderate Area Potential	
Off-street parking spaces	134.68 ha	95.62 ha	
On-street parking spaces	279.48 ha	198.68 ha	
Roadway area	799 ha	567.29 ha	
	1,213.16 ha	861.59 ha	Total Traffic Area Size

4.2 Results 2 – The Three Conversion Options

4.2.1 Results 2 – Convertible Area per Option

I developed three Options, i.e. Option 1 "traffic-free", Option 2 "traffic-calmed with open spaces", and Option 3 "traffic-calmed", in which different traffic area sizes are convertible and nonconvertible. The traffic area sizes are based on the calculations of the maximum and moderate conversion potential from the first results section. The values and the respective percentages of the total area of Berlin's center of the convertible area are given for each option and each traffic area type in Table 4.

Table 4: Results 2. Convertible area of the three options, i.e. Option 1: "traffic-free", Option 2: "traffic-calmed with open spaces", Option 3: "traffic-calmed" per traffic area type.

Traffic area type	Convertible area of Option (1)	Convertible area of Option (2)	Convertible area of Option (3)	
Off-street parking spaces	134.68 ha	134.68 ha	95.62 ha	
On-street parking spaces	279.48 ha	198.68 ha	198.68 ha	
Roadway area	799 ha	567.29 ha	567.29 ha	
	1,213.16 ha	900.65 ha	861.59 ha	Total Convertible Area
	13.9 %	10.3 %	9.9 %	Percentage of Total Study Area

“Traffic-free” Option 1 indicates a conversion of the total amount (100%) of traffic areas. By that, 1,213.16 ha, i.e., 13.9% of the total study area, can be converted. Option 2, the “traffic-calmed with open spaces” option, indicates converting 71% of the on-street parking spaces, the roadway area, and 100% of the off-street parking spaces. Hence, in total 900.65 ha is available for conversion, accounting for 10.3% of the total study area. “Traffic-calmed” Option 3 means that 71% of all traffic area types can be converted, while the rest remain as traffic areas. By that, 861.59 ha can be converted in Option 3, accounting for 9.9% of the total study area. All these quantities can be found in Table 4.

4.2.2 Results 2 – Visualization of the Convertible and Nonconvertible Traffic Areas

In the following section, an example extract of the study area illustrates how much traffic area can be converted depending on the conversion option. The extract is located within the planning area “Kaiserin-Augusta-Allee” (district Charlottenburg) and has a total area of 20 ha.

Figures 7-9 illustrate A) the traffic area that can be converted and B) the traffic area that remains as such (nonconvertible) – if included – per conversion option. In Option 1, all traffic areas are convertible and visualized in three shades of green (see Figure 7). Dark green displays the convertible off-street parking spaces, medium green shows the convertible on-street parking spaces, and light green visualizes the convertible roadway area. The total area that can be converted here is 4.59 ha, which accounts for 22.95% of the total area of the extract of the study area. All quantities can be seen in Table 5. Figure 8 displays Option 2, in which the convertible area is visualized in the same shades of green as in Figure 7. The total convertible area is 3.7 ha, which is 18.5% of the total area of the extract (see Table 5). The areas that remain as traffic areas (nonconvertible) are colored differently. The remaining on-street parking spaces are blue, and the effective roadway area is red (see Figure 8). Figure 9 visualizes the traffic area (convertible and nonconvertible) of Option 3. The chosen colors are the same as for Figures 7 and 8. The nonconvertible off-street parking spaces in Option 3 are displayed in yellow. The total traffic area here is 2.95 ha, accounting for 15.75% of the extract’s total area. All quantities are shown in Table 5.

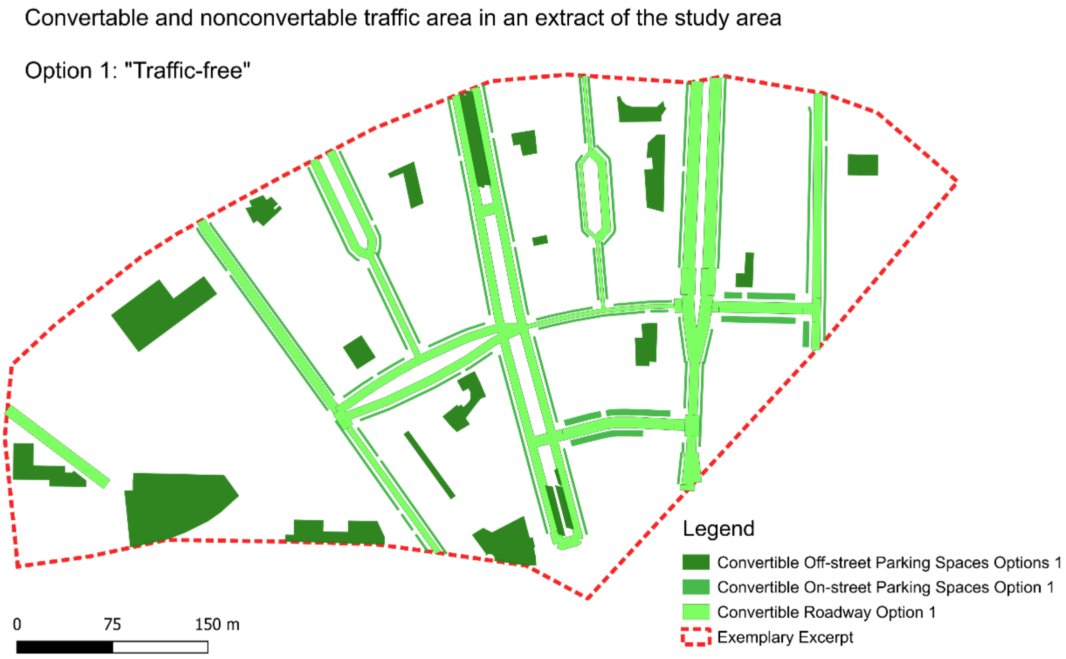

Figure 7: Convertible area of the three traffic area types in an extract of the study area, as in Conversion Option 1. The convertible roadway area is visualized in light green, the convertible on-street parking spaces are medium green and the convertible off-street parking spaces are dark green. Own visualization based on data from OpenStreetMap (OSM) and the dataset "parking segments" provided by OpenStreetMap contributors (n.d.b).

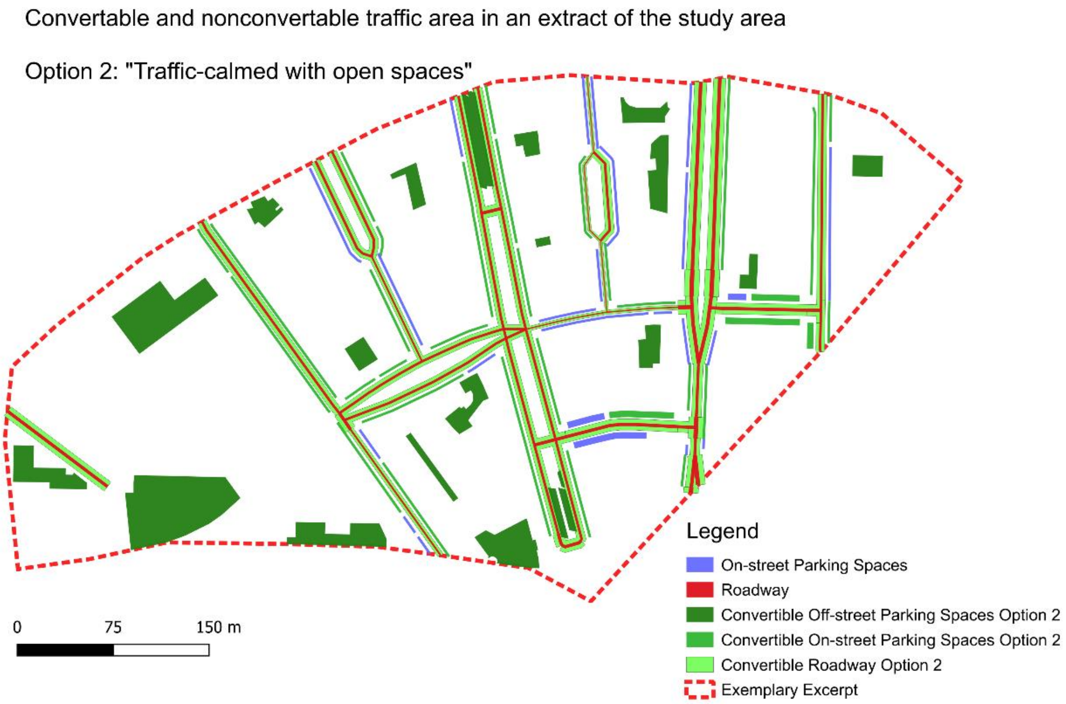

Figure 8: Convertible and nonconvertible areas of the three traffic area types in an extract of the study area, as in Conversion Option 2. The convertible areas are visualized in shades of green, as in Figure 8. The nonconvertible roadway area is red, and the nonconvertible area of the on-street parking spaces is blue. Own visualization based on data from OpenStreetMap (OSM) and the dataset "parking segments" provided by OpenStreetMap contributors (n.d.b).

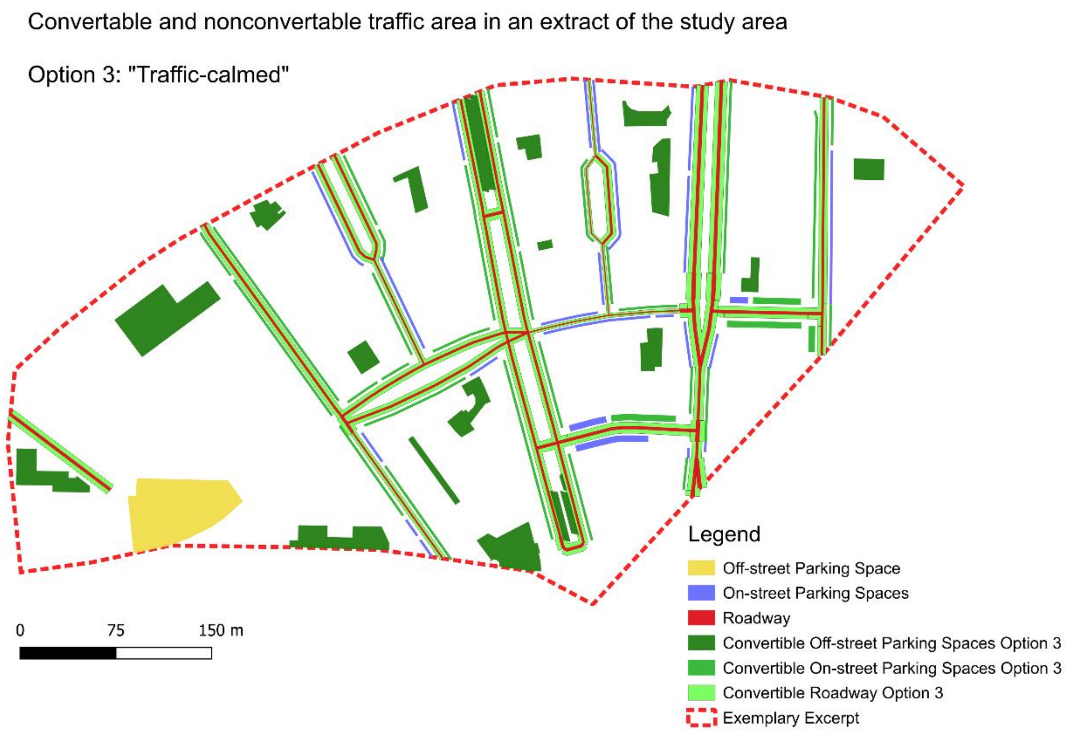

Figure 9: Convertible and nonconvertible areas of the three traffic area types in an extract of the study area, as in Conversion Option 3. The convertible areas are visualized in shades of green, as in Figure 8. The nonconvertible roadway area is red, the nonconvertible area of the on-street parking spaces is blue, and the nonconvertible off-street parking space is yellow. Own visualization based on data from OpenStreetMap (OSM) and the dataset "parking segments" provided by OpenStreetMap contributors (n.d.b).

Table 5: Convertible traffic area of the three options, i.e., Option 1: "no-traffic", Option 2: "calmed-traffic with open spaces", Option 3: "calmed-traffic" of the exemplary extract of Berlin's center.

Traffic area type	Convertible area of Option (1)	Convertible area of Option (2)	Convertible area of Option (3)	
Off-street parking spaces	1.52 ha	1.52 ha	0.77 ha	
On-street parking spaces	0.96 ha	0.68 ha	0.68 ha	
Roadway area	2.11 ha	1.5 ha	1.5 ha	
	4.59 ha	3.7 ha	2.95 ha	Total Convertible Area
	22.95%	18.5%	14.75%	Percentage of Total Study Area

4.3 Results 3 – Relation of Traffic Area and Green Space Provision

Objective C is to display the relationship between the traffic area and one of the environmental justice indicators – Green Space Provision – per conversion option across the planning areas, to prioritize planning areas for a traffic area conversion.

Figure 10 illustrates the relative traffic area values and the green space provision of conversion Option 1. The relative traffic area values are displayed on the y-axis, and the three categories of green space provision are displayed on the x-axis. As Figure 10 displays a jitter plot, the precise position on the x-axis is inconsequential, except for belonging to one of the three categories. However, the greater the scatter of the points, the more similar traffic area values there are. Labeled points (i.e., planning areas) are those with relative traffic area values within the 95th percentile of all traffic area values. Compared to the other planning areas, the proportion of traffic areas within the built-up area is therefore highest here.

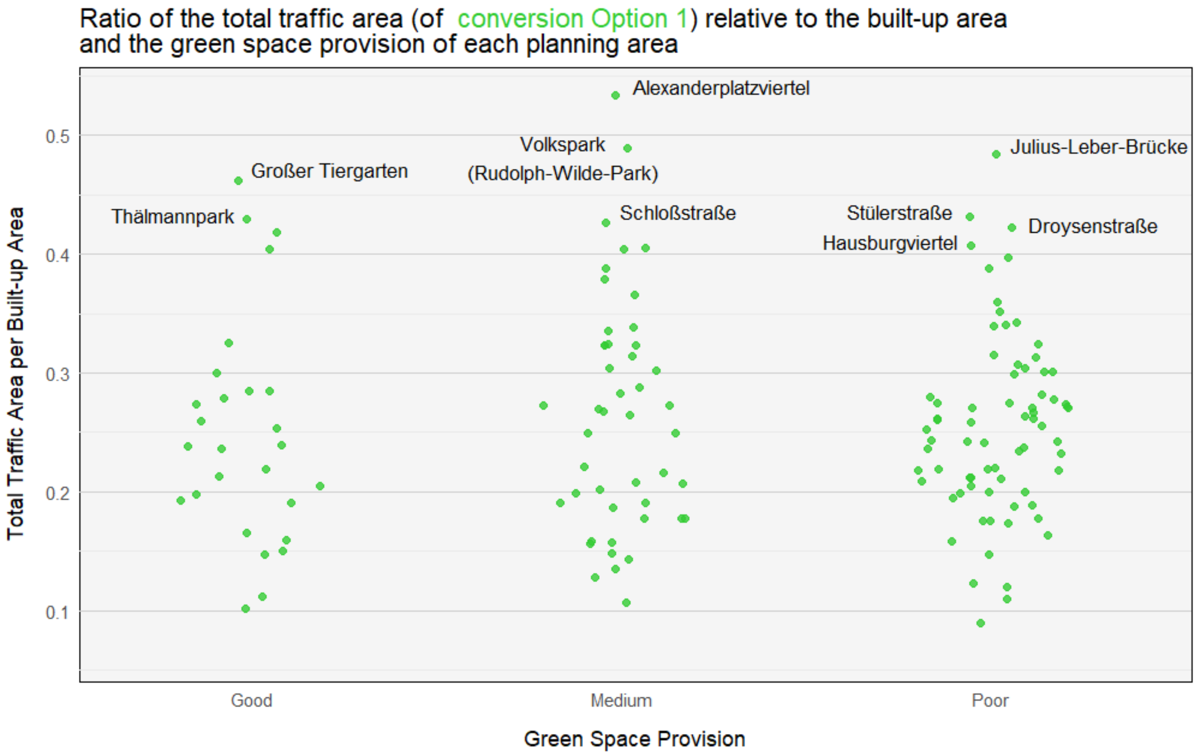

*Figure 10: **Ratio of A) the relative traffic area values of all three traffic area types (y-axis) of Option 1 and B) the green space provision (x-axis) of all planning areas in the study area.** The traffic area is shown relative to the built-up area. High relative traffic area values indicate that much of the built-up land is used for transportation infrastructure. Labeled planning areas have relative traffic area values in the top 95th percentile of all traffic area values. Own visualization based on 1) data from OpenStreetMap (OSM) and the dataset "parking segments" provided by OpenStreetMap contributors (n.d.b); 2) the built-up area as classified after IÖR (n.d.) and obtained from Berlin's land-use map provided by SenStadt (2022a); and 3) the environmental justice map Green Space Provision provided by SenMVKU (2022b).*

Planning areas with relative (rel.) traffic area values in the 95th percentile and ‘good’ green space provision are ‘Großer Tiergarten’ and ‘Thälmannpark’. The ones with a ‘medium’ green space provision are ‘Alexanderplatzviertel’, ‘Volkspark (Rudolph-Wilde-Park)’ and ‘Schloßstraße’. Planning areas with ‘poor’ green space provision and traffic area values in the 95th percentile are ‘Julius-Leber-Brücke’, ‘Stülerstraße’, ‘Droysenstraße’, and ‘Hausburgviertel’ (see Figure 10). Table 6 represents all the mentioned planning areas, with their respective relative traffic area values and green space provision categories visualized in Figure 10. The values on the right of the thick line in Table 6 represent corresponding values not displayed in Figure 10. These include the relative traffic area values of Option 2 and 3, the absolute (abs.) traffic areas of all options, and the proportion of the inhabited area to the built-up area. Plots of Options 2 and 3 can be found in Appendix 4, as the labeled planning areas are identical across all three conversion options.

Table 6: Green space provision, relative traffic area values per conversion option, absolute traffic area values per conversion option, and the proportion of the inhabited area to the built-up area of the labeled planning areas of Figure 11.

Planning area	Green provision	rel. traffic area value (Option 1)	rel. traffic area value (Option 2)	rel. traffic area value (Option 3)	abs. traffic area (Option 1)	abs. traffic area (Option 2)	abs. traffic area (Option 3)	Proportion of inhabited to built-up area
Großer Tiergarten	good	0.4622	0.3396	0.3281	355 894 m²	261 546 m²	252 685 m²	7.8 %
Thälmannpark	good	0.4292	0.3170	0.3047	77 236 m²	57 057 m²	54 837 m²	45.8 %
Alexanderplatz-viertel	medium	0.5337	0.3836	0.3789	320 156 m²	230 100 m²	227 311 m²	37 %
Volkspark (Rudolph-Wilde-Park)	medium	0.4889	0.3700	0.3472	151 708 m²	114 808 m²	107 713 m²	75 %
Schloßstraße	medium	0.4267	0.3049	0.3029	125 142 m²	89 427 m²	88 851 m²	92 %
Julius-Leber-Brücke	poor	0.4841	0.3437	0.3437	31 795 m²	22 574 m²	22 574 m²	100 %
Stülerstraße	poor	0.4312	0.3093	0.3062	95 587 m²	68 555 m²	67 867 m²	57.7 %
Droysenstraße	poor	0.4222	0.3103	0.2997	64 760 m²	47 602 m²	45 979 m²	87.7 %
Hausburgviertel	poor	0.4068	0.2909	0.2888	80 764 m²	57 764 m²	57 342 m²	87.6 %

5 Discussion

In this study, the traffic area intended for motorized traffic in Berlin's center was estimated, consisting of the roadway area and the areas of the on-street and off-street parking spaces. These area sizes could enable urban planners to quantify changes in the traffic area in the event of traffic calming. Traffic calming, and traffic area conversion can bring many benefits to urban life, e.g. by converting them into health-promoting urban green spaces (UGSs). For this reason, I developed three conversion options to demonstrate how area-based conversion measures could look in the study area. However, the conversion of traffic areas into green spaces in areas that are already sufficiently equipped with green spaces can lead to further environmental injustices. Therefore, planning areas in Berlin's center were revealed that are most affected by a poor green space provision. To prioritize planning areas for converting traffic area, I identified planning areas with poor green space provision and simultaneously a possibly high area potential for conversion.

5.1 Traffic Area Potential in Berlin's Center

For a genuine and effective shift towards ecological transportation practices, it is essential to quantify traffic areas to identify potential for change and make transformations visible and measurable. However, there is a lack of quantitative data on traffic areas, including the center of Berlin. Therefore, this study's area estimation of the three traffic area types is the first comprehensive estimation of the total traffic area designated for motorized traffic in Berlin's center. My results (Results 1) reveal that around 14% of Berlin's center is occupied by motorized traffic in total. Hence, this area is the maximum area potential in which traffic area-related traffic calming measures can be taken. To give a comparison, the sum of all green spaces in Berlin's center accounts for 12% of the total area (provided by SenMVKU, 2024a). In addition, the moderate area potential in this study indicates that almost 10% of the study area is convertible in the event of a traffic calming. The moderate area potential includes some motorized traffic to increase feasibility and acceptance among the population and the politics, cars must still be integrated into Berlin's city center, as cities have developed to be car-friendly (Southworth, 2005). The largest share (66%) of the total traffic area potentials is attributed to the effective roadway area. This indicates that roadways have substantial spatial potential to make a significant impact on traffic conversion measures.

The only traffic area size that can be compared to other existing data is the one of the on-street parking space area. Data on the on-street parking spaces in Berlin's center were published in November 2023, shortly after my data analysis, by Berlin's Senate of Mobility, Traffic, Climate

Protection and Environment (VIZ, n.d.). The total area of the on-street parking spaces of this dataset (updated in March 2024) in the study area is around 264 ha (provided by SenMVKU, 2024b). This is 5.6% less than the area I calculated from the on-street parking space dataset I created. A visual examination of both datasets in QGIS revealed that street trees in the Senate's dataset are not included in the dataset of the OSM-parking-space-project, I used. This may be one explanation for the discrepancy in area.

However, using the data of the OSM-parking-space-project for the on-street parking spaces, as well as using OSM data for the roadway area and the off-street parking spaces, provides many advantages. For example, the mapped features of OSM are increasing in time and the datasets by the OSM-parking-space-project are continuously updated. By that, the on-street parking space dataset of the OSM-parking-space-project are probably more up-to-date than the data of Berlin's Senate. It can also be assumed that OSM data becomes more accurate over time. Therefore, all of my traffic area datasets can be updated for future work. Additionally, the data can be compared with other German cities thanks to the standardized mapping schema of the OSM-parking-space-project (OpenStreetMap contributors, n.d.b) and of the OSM data (OpenStreetMap, n.d.). This, for instance, means that traffic areas of different cities or areas can be compared, while a comparison between data from different senate administrations of different cities may not suggest this.

Both, the maximum and the moderate area potential can provide urban planners and decision-makers with a strategic basis for traffic area conversion and traffic-calming measures, as conversions can be quantified. Additionally, since there is no comparable analysis that calculates the minimum traffic space requirements for some selected motorized vehicles if car traffic is reduced, this study provides an initial estimate of these requirements in Berlin's center. Moreover, the area potential estimations of the three types of traffic areas (off-street parking spaces, on-street parking spaces and the roadway) can also be used separately for planning traffic-calming measures. Depending on the specific context or objectives, one of the traffic area types may be more suitable for conversion measures and in such a case, the area potential of that specific type can be used.

5.2 Three Options for Converting Traffic Areas

Motorized traffic, directly or indirectly, by ecological challenges such as air and noise pollution, can lead to several health-threatening challenges for urban residents (e.g., WHO, 2023; WHO 2024; Petralli et al., 2014; Mackett & Brown, 2011). Therefore, converting traffic areas can potentially create a healthier urban environment, as a study by Mueller et al. (2020) about Barcelona's superblocks has shown. In practice, cities around the world are implementing measures to reduce motorized traffic (Doheim et al., 2020). The amount of space that may be converted depends on the traffic calming measures embedded in policy strategies. Depending on how much and what kind of traffic areas are to be converted, various conversion options could come into play. Several possibilities exist for converting traffic areas, such as implementing bicycle infrastructure or creating spaces or facilities for recreation or socializing, as in Oslo or Paris (Doheim et al., 2020; Tennøy & Hagen, 2020). Results 2 introduces three options for convertible areas sizes and their potential distribution in Berlin's center. Possible alternative uses depending on the convertible area size and distribution of each conversion option are presented in the following. According to Nieuwenhuijsen and Khreis (2016), a comprehensive consideration of different traffic calming measures can provide better insights for policymakers and equip them with data that may guide the decision-making process.

5.2.1 "No-traffic" – Option 1

In Option 1, the maximum area potential of the traffic area is released for conversion. Thus, the remaining mobility infrastructure includes sidewalks, bikeways, and non-road-based public transport, as these are not part of the traffic areas defined in this study. However, the urban focus on cars has led to the growth of cities, thereby compromising walkability and making cars indispensable (Southworth, 2005). Probably because of that, I was not able to find one city worldwide that is entirely car-free.

While some motorized vehicles, like emergency vehicles, are essential, reducing car traffic could help achieve WHO's "healthy urban planning" goals: a safe, healthy environment, active lifestyles, social cohesion and accessible housing and amenities (Barton & Grant, 2011). Banning cars in Berlin's center could, e.g., decrease accidents, noise and air pollution, and emissions (EEA, 2020; Khreis, 2020; WHO, 2023; WHO, 2024). Additionally, converting traffic areas for cycling and into UGSs and exercise facilities can foster physical health and social cohesion (e.g. Cattell et al., 2008; Ward Thompson & Silverinha de Oliveira, 2016; Danis et al., 2014; Ma et al., 2019; Dash et al., 2024). Because of that, these measures are intended by Berlin's strategy for 2030 (Senatskanzlei Berlin, 2022) and have already been implemented in Oslo and Paris (Doheim et al., 2020; Tennøy & Hagen, 2020).

Moreover, convertible spaces could meet demands for affordable housing and leisure areas, further supporting healthy urban living as proposed by WHO's "healthy urban planning" (Barton & Grant, 2011). Appendix 5 presents a more detailed description of the aspects described. Table 7 represents pros (+) and cons (-) that a conversion as in Option 1 may indicate. In conclusion, although the conversion potential into health-promoting spaces is high, I assume that converting all traffic areas is unrealistic but can demonstrate the theoretical conversion potential.

Table 7: Evaluation matrix of conversion Option 1.

	Aspect	Summary	Evaluation
Option 1	Eliminated traffic infrastructure	Since cities have developed primarily for cars (Southworth, 2005; Newman et al., 2015), eliminating traffic infrastructure is unlikely.	-
	Essential Motorized Services	Some motorized vehicles (ambulances, fire trucks, etc.) are indispensable.	-
	Public Transport Limitation	Limited motorized traffic requires comprehensive public transport (Jensen et al., 2021), which is limited by excluding road-based public transport.	-
	Health and Safety Benefits	Reducing motorized traffic can decrease deaths and injuries from road accidents (WHO, 2023), noise (EEA, 2020) and air pollution (WHO, 2024; Khreis, 2020)	+
	Climate impact	Reducing motorized traffic can lower CO_2 emissions (UN n.d.).	+
	Conversion possibilities	There are many conversion possibilities due to the convertible area of all traffic area types.	+
	Promotion of healthy lifestyles	Converting traffic areas can support physical activity by encouraging active mobility modes (c) and by converting them into open spaces (Ma et al. 2019; Danis et al., 2014).	+
	Promotion of social cohesion	Converting traffic areas into street markets, green spaces, or sports centers can strengthen social cohesion (Cattell et al. 2008; Dash et al. 2024; Peters et al. 2010).	+
	Access to Housing and Facilities	A conversion of the traffic areas gives opportunities to provide high-quality housing and community amenities.	+

5.2.2 “Traffic-calmed with open spaces” – Option 2

In contrast to Option 1, Option 2 provides for limited motorized traffic (on on-street parking spaces and the roadway). On the one hand, this allows some vehicles to drive and park in the study area, which may be indispensable in a city center as large as Berlin’s (8,746 ha). On the other hand, motorized traffic is reduced, which can positively affect city dwellers and the environment, as described before. The study by Mueller et al. (2020) showed that Barcelona's Superblocks could prevent premature deaths due to air pollution, and noise pollution, decrease temperature, and increase the provision of UGS.

Although the conversion potential in Option 2 is reduced, compared to Option 1, two significant effects can be achieved by converting the areas: Proximity and Connectivity. These two effects, first, support converting the traffic areas into UGSs because both enhance the positive effects of UGSs (e.g., Coombes et al. 2010; Shanahan et al. 2015; Hartig & Lindal, 2021; FitzGibbon et al., 2007), as described in more detail in Appendix 5. Second, traffic areas can be converted into bicycle infrastructure, encouraging the use of bicycles (Ward Thompson & Silverinha de Oliveira, 2016). As, acording to my results, the effective roadway area accounts for the largest share of the total traffic area in Berlin's center, a narrowing of the roadway may offer a substantial area to be converted. Table 8 represents the pros (+) and cons (-) of the conversion as in Option 2. Aspects that are repeated from Option 1 are not listed again here. In conclusion, several health-promoting areas can be created while the mobility of different traffic users is ensured, making Option 2 probably more feasible than Option 1. Additionally, off-street parking spaces may serve as large green spaces, enhancing the residents' health, but these cannot serve as such in Option 2.

Table 8: Evaluation matrix of conversion Option 2.

	Aspect	Summary	Evaluation
Option 2	Traffic infrastructure	Retention of some on-street parking spaces and the roadway infrastructure.	+
	Essential Motorized Services	Some indispensable motorized vehicles can park on-street and drive on the roadway.	+
	Limited conversion possibilities	Conversion possibilities are limited due to remaining on-street parking spaces and roadway areas.	-
	Promoting healthy lifestyles due to proximity of the convertible areas	Converting traffic areas into UGSs can particularly encourage physical activity by increasing the visitation rate of UGS near to the people's lives (Coombes et al. 2010). It can further increase the attractiveness of the roads, encouraging to choose an active mobility mode (WHO, 2018).	+

	Promoting social cohesion due to proximity of the convertible areas	Converting traffic areas into UGSs near people’s lives can promote social cohesion and interaction (Cattell et al. 2008; Francis et al. 2012).	+
	Cooling effect due to proximity of convertible areas	Converting traffic areas into UGSs provides people with cooling due to UGSs' proximity (Shanahan et al. 2015).	+
	Promoting healthy lifestyles due to connectivity of convertible areas	Converting traffic areas into UGS provides residents with opportunities such as running routes (Ammon & Langenbrinck, 2022), or spaces for recreation (Hartig & Lindal, 2021).	+
	Promoting mental health due to connectivity of convertible areas	Converting traffic areas into UGS may enhance species richness (FitzGibbon et al., 2007), which may positively influence the perceived ability to recover (Lorenzo et al., 2016).	+
	Conversion possibilities of the off-street parking spaces	Some off-street parking spaces may serve as play areas, quiet zones, meeting places (Rittel et al., 2014), or as nature experience spaces (Molitor & Martens, 2021).	+
	Elimination of off-street parking spaces	Off-street parking spaces may be needed, e.g., for delivery vehicles or scheduled buses, when not in use.	-

5.2.3 “Calmed-Traffic” – Option 3

In contrast to Option 2, Option 3 also provides off-street parking spaces to remain as such. Hence, the transport network remains as it currently is, while its function changes in quantity. Since the on-street parking space conversion and the roadway area conversion were discussed above and shown in Table 8, Table 9 shows the pros (+) and cons (-) of the conversion possibilities regarding the off-street parking spaces. A more detailed description of Table 9 can be found in Appendix 5. If the largest off-street parking spaces are retained as such, around 1,900 of the 2,000 off-street parking spaces in the study area can be converted. These may be converted into pocket parks as they can contribute to a healthy environment despite their small size (Nordh et al., 2009). In conclusion, all three traffic area types can be retained in their structure despite conversion, while parts of all three traffic areas can be converted into health-promoting areas.

Table 9: Evaluation matrix of conversion Option 3.

	Aspect	Summary	Evaluation
Option 3	Traffic infrastructure	Retention of all three traffic area types.	+
	Limited conversion possibilities	Conversion possibilities are limited due to remaining on-street and off-street parking spaces and roadway areas.	-
	Conversion possibilities of the off-street parking spaces	Some off-street parking spaces can be converted into pocket parks, making UGSs potentially accessible to many residents (Cohen et al., 2014).	+

5.3 Prioritization of the Planning Areas

Although the conversion of traffic areas into areas such as UGS has many positive effects on urban health, it can lead to the upgrading and thus displacement of population groups e.g. with low income (Anguelovski et al., 2018; Rigolon & Németh, 2020). To counteract this effect, I propose to prioritize planning areas with a green space deficit for a traffic area conversion. This aligns with the Berlin Strategy 2030, which aims to develop green spaces with a green deficit (Senatskanzlei Berlin, 2022). Furthermore, green space provision as a prioritization indicator can highlight additional inequities, as limited access to UGS often correlates with lower socio-economic status and health risks (Wüstemann et al., 2017; EEA, 2022; Farkas et al., 2022). Therefore, converting traffic areas into UGS in the prioritized planning areas could also promote a more evenly distribution of goods and/or services, also referred to as distributional justice (Low & Iveson, 2016).

In addition, the planning areas with the most traffic areas relative to the built-up area may indicate an overabundance of space dedicated to motorized traffic. The traffic area conversion potential is probably relatively high in these planning areas, which may mean that conversion measures can have a particularly large effect here. Furthermore, planning area Julius-Leber-Brücke could be given special priority, as its land use is 100% residential. In this way, green areas may directly benefit the local population, as green spaces close to residential areas have been shown to provide many different health and quality of life benefits (Cattell et al., 2008; Coombes et al., 2010; Francis et al., 2012; Cohen et al., 2014), as described above. In general, the aggregation of traffic areas to Berlin's smallest spatial unit (the planning areas) could also enable conversion measures to be adapted to the needs of local conditions. The reason for this is that the planning areas are selected in such a way that they achieve the highest possible homogeneity e.g., in terms of similar settlement types and socio-economic structures (SenStadt, n.d.c), which presumably allows most needs within each area to be addressed. In conclusion, the prioritization proposals mentioned have many advantages and could thus show urban planners and decision-makers a possible prioritization. If other factors, such as the absolute traffic area values per planning area, play a role in the planning of conversion measures, the results of this study can also provide these values.

5.4 Limitations

Some limitations in selecting and processing the three traffic area datasets must be mentioned. First, I used a probabilistic approach to fill in the missing width and length information of the 'parking segments' dataset of the OSM-parking-space-project to create the datasets of the on-street parking spaces and the effective roadway area. As a result, parking segments with incomplete data were assigned percentages indicating the proportion of each segment where parking is likely to occur and in what orientation (i.e., the parking width). This approach introduces uncertainty into the calculations, as the actual dimensions may not always be accurate. The same applies to the roadway areas, where information on their width is missing. Additionally, due to the probability approach, no spatial analysis can be performed with the supplemented data.

Second, some parking segments were incorrectly mapped twice in the 'parking segments' dataset. I attempted to account for these duplicates during the data processing, but, likely, not all of them were successfully removed. This has led to inaccuracies in the parking space calculations and the roadway width as well. Third, bicycle parking spaces and some bicycle lanes are still part of the effective lane width. As a result, the roadway area is likely overestimated in some instances. Additionally, the applied standard width values do not apply to one-way streets, which again overestimates the roadway area. Fourth, the dataset used for the off-street parking spaces consisted solely of surface parking lots, meaning that other types of parking infrastructure, such as underground or multistoried garages, were not included in my calculations. Hence, the identified parking potential does not fully account for the total off-street parking capacity in the study area.

The moderate area potential, I have defined, also has some limitations. First, the traffic area requirement for the defined car use in the moderate area potential was based exclusively on on-street parking space exceptions. Defining exceptions for the other two traffic area types (off-street parking spaces and the roadway) would make the moderate area potential more accurate. For example, scheduled buses and trams may be included to define the necessary roadway area or delivery vehicles for the off-street parking spaces. Second, I used the current stock of car-sharing cars and taxis (first and second exception) in Berlin to determine the number of on-street parking spaces necessary. A demand analysis of the vehicles would lead to a more accurate result. I also suggest developing a fair and objective selection process to refine the estimate of people who depend on private cars (third exception). This process could consider groups such as people needing care, caregivers, or hardship cases (Initiative Volksentscheid Berlin autofrei, 2021). Third, traffic law information for developing the moderate area potential must be included, e.g., to ensure minimum roadway widths for ambulances, etc. Lastly, other essential vehicles, such as ambulances, fire trucks, delivery vans, public road transport, etc., must be considered when converting traffic areas.

The suggested alternative uses of the traffic areas, to address RQ2, are based on general statements about which areas can create healthier cities according to the WHO's goals for “healthy urban planning” (see Barton & Grant, 2011) and do not refer to the explicit traffic areas in Berlin’s center. A concrete analysis of how the traffic areas could be used alternatively requires, for example, demand analyses. A possible conflict of use could be converting the traffic areas as fallow or building land. If that is the case, a comprehensive nature conservation assessment (e.g., about their function as habitat or recreation area) of these areas may be required to identify their importance for nature conservation (Hansen et al., 2012). In addition, in Berlin, for example, creating affordable housing is one of the biggest challenges as the city grows (Senatskanzlei Berlin, 2022).

In addition, I solely chose the spatially specific convertible traffic areas due to their proximity and connectivity, as these can enhance the quality of UGSs. However, the specific traffic areas to be converted may depend on other factors. For instance, the selection of on-street parking spaces for conversion could depend on their frequency of use, as less frequently used areas may be more suitable for conversions. Moreover, the choice of areas for conversion could be guided by identifying specific community needs at the respective locations as well. For example, areas lacking in essential facilities might be prioritized for conversion into the specific needed facility. When converting traffic areas into green spaces, it may also be beneficial to consider how new green spaces could integrate with existing ones (including trees) to create a green network. Furthermore, instead of uniformly narrowing all roadways, attention should be given to maintaining a minimum width to comply with legal requirements.

Furthermore, although UGSs can be a suitable conversion measure, as described above, they must be planned, designed, and built so that they actually fulfill their benefits (Badar & Bahadure, 2020). For example, the design of green spaces should be adapted to the conditions of the location and the motivation and purpose of the residents living, working, or spending time in the respective neighborhood (DRL, 2006; Gehl, 2006 in Francis et al., 2012). One reason is that UGSs can only develop their health-promoting potential if they are high quality, i.e., perceived as attractive (Sugiyama et al., 2010). However, as it is impossible to meet all residents' needs, ensuring the broadest possible variety of (public) open spaces with appropriate facilities and proximity to city residents is crucial (Cattell et al., 2008; Francis et al., 2012). Moreover, urban planners must be aware of ‘green gentrification’, as UGSs in a neighborhood may increase housing prices and therefore exclude certain community groups (Anguelovski et al., 2018; Rigolon & Németh, 2020).

Another challenge with converting traffic areas is the accommodation of the existing cars in the study area. Although it can be assumed that the number of privately owned cars decreases when traffic is calmed (Baptista et al., 2014; Jochem et al., 2020), some journeys may only be made by car. To account for that, multi-story parking garages around Berlin’s center, as planned in Buch, one of Berlin's new urban neighborhoods (SenStadt, 2022b) may be built. Since the study area is enclosed by the ring-shaped urban railway of Berlin (called "Ringbahn"), parking garages may be constructed at its stations. Furthermore, privately owned vehicles may be parked privately, e.g., in residential garages, as in Oslo's traffic conversion program (Oslo Kommune, 2019).

In addition, when reducing parking spaces, for example, converting measures such as greening or furnishing must be created simultaneously (Wylie, 2019). Otherwise, the measures could be met with resistance from the population (ibid.). Similarly, to avoid simply eliminating one mobility option by calming individual motorized traffic, other forms of mobility should be expanded at a similar time (Nieuwenhuijsen et al. 2019). Careful consideration should also be given to how traffic conversion or traffic calming measures are communicated to the community. For example, the municipality should focus on naming the advantages of parking space removal (Wylie, 2019). Additionally, participatory processes in traffic conversion measures may increase acceptance in the urban population (Nieuwenhuijsen et al., 2017).

When prioritizing planning areas, other indicators besides green space provision may be included. Noise, for example, can be an essential factor as road transport affects more people in the EU than other noise sources (EEA, 2020). Furthermore, noise pollution significantly threatens human health (WHO, 2011) and the level of noise pollution is particularly high in the study area, as is the supply of green spaces (SenMVKU, 2022a). In addition, the multiple burden maps (SenMVKU, 2022a) could also help to find suitable prioritizations. One of these maps integrates all four environment-related indicators (air, noise, thermal pollution, green space supply) and the 'social disadvantage' indicator. By using this integrated inequity map, the most polluted planning areas could be prioritized and thus possibly counteract distributional environmental injustice the most.

It can also be questioned whether high traffic area values relative to the built-up area mean a large conversion potential. Following Oslo's approach of focusing efforts to ensure a visible impact in specific urban areas for traffic area conversion measures (Oslo kommune, 2019), planning areas with high absolute traffic areas could be prioritized. In addition, a high share of residential areas may not ultimately indicate that most residents would benefit from a traffic area conversion, as that also depends on the building structure. Planning areas with a lower proportion of housing but more high-rise buildings could accommodate more residents. Therefore, for example, population density would be a variable that could be considered in prioritization ideas.

6. Conclusions

In conclusion, this study provides the first comprehensive estimate of the traffic area: the off-street and on-street parking spaces and the effectively used roadway area in Berlin's center (i.e., within the "Ringbahn"). My results reveal that Berlin's center has a traffic conversion potential of 1,213.16 ha if no traffic areas are allocated for motorized traffic, representing the 'maximum area potential'. Thus, traffic areas account for 14% of the total area within the study area, which potentially represents a substantial spatial potential for traffic area conversion in the event of implementing traffic-calming measures. Even if the accuracy of the data has its limits, due to data availability and conceptual assumptions, the result represents a decisive first step toward quantifying the area occupied by motorized traffic in Berlin's center. Additionally, I combined two open-source data sources to generate this study's traffic area datasets: OSM data and a dataset by an OSM project. As the mapped features of OSM are increasing in time and the datasets by the OSM-parking-space-project are continuously updated, my traffic area datasets can be updated for future work. Further, the methodology can be replicated and refined in subsequent studies, due to reproducible code.

The 'moderate area potential' allows some motorized vehicles to drive and park in the study area, resulting in 861.59 ha, i.e., almost 10% of the total area of the study area. By that, I have made an initial estimate of the space required for motorized traffic. By refining this estimate, for example, through needs assessments and by including all motorized vehicles that are essential in Berlin's center, it may be possible to determine how much traffic space must remain in place during a traffic-calming process. Such quantification is essential for a seriously taken shift towards ecological transportation practices, as it provides a starting point against which changes can be measured and evaluated. For example, the data can be used to determine an area conversion potential depending on the conversion target, the location, and the respective area size.

In addition, calming traffic and conversion measures offer many advantages for the inhabitant's health and the urban environment. My three conversion options may provide possible convertible areas and respective alternative uses in three different approaches. However, no alternative uses can be proposed solely based on the traffic area sizes. Finding suitable conversions is complex because of land use conflicts and the demand for needs analyses. On the other hand, urban green spaces can offer various benefits for the urban environment and its population. Particularly, the proximity to residents' lives and the connectivity of traffic areas could help to create green spaces that are especially health-promoting and ecologically valuable.

Lastly, the comparison of traffic area values and the provision of green space in the study area's planning areas revealed areas that could be prioritized for traffic area conversion. The approach of prioritizing planning areas in the center of Berlin can offer a way of preventing an unfair upgrading of certain areas through the conversion of traffic areas. By prioritizing planning areas that potentially have a high conversion potential and at the same time lack green spaces, environmental injustice could be improved to a certain extent.

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7. Appendix

This section will present more information to clarify decisions on the methods section, supplemental results material, as well as a more detailed description of the second discussion section. Appendix 1 covers the data sources OpenStreetMap (OSM) and the OSM-parking-space-project. Appendix 2 provides additional information about the data processing and Appendix 3 shows assumptions and decisions that I made for the analysis. Appendix 4 shows the third results section of conversion Option 2 and 3 and Appendix 5 explains the three conversion options in more detail.

7.1 Appendix 1 – Data Sources

OSM. OSM is a community-based mapping service whose accumulated contributors (i.e., volunteers) per month is growing linearly (OpenStreetMap Wiki contributors, 2024b). In 2023, there were around 50,000 active contributors per month, who made around 120,000,000 edits per month (ibid.). Since OSM is free and released with an open-content license OSM is also convenient for users (OpenStreetMap Wiki contributors, 2024a). To access OSM data, one can select one or more geographical objects that are categorized in "keys" in OSM terminology. These are, for example, 'amenity', 'building', 'highway' etc. A further specification with the so-called “value” of the selected “key” can be, for example, 'parking'. However, "parking" can also be used as a "key". If one wants to specify the parking spaces in more detail, for example. in multi-story parking garages, the "value" of "multi-storey" is queried.

OSM-parking-space-project. The OSM-parking-space-project is part of the voluntary work of OpenStreetMap’s working group called ‘traffic turnaround’ (originally: Arbeitsgruppe Verkehrswende). The working group provides three datasets: ‘parking lanes’, ‘parking spaces’, and ‘parking segments’ (OpenStreetMap contributors, n.d.). The ‘parking lanes’ represent the OSM highway line with an offset, ‘parking spaces’ are calculated points representing a parking spot and ‘parking segments’ are the smallest part of a street with parking information (gislars et al., 2023). The last update occurred on the first of July 2024 (last access: 7. July 2024). The dataset ‘parking segments’ contains the smallest part of a street with parking information on each side of the road where parking is or is not allowed (ibid.). Here, road edges with an offset to the OSM road line (‘highway’ in OSM) are, e.g., mapped to be no-parking, parallel-parking, perpendicular-parking, or diagonal-parking (Seidel & OpenStreetMap-Contributors, 2021). Intersections, bus stops, sidewalk crossings, and building entrances are inter alia omitted from on-street parking (as they call it subtraction model) (ibid.). Further, for every segment, the road type (column ‘highway’) is indicated, as well as information about the width (depending on the parking orientation) and the length of each segment.

7.2 Appendix 2 – Data Processing

To decide which planning area should be excluded or maintained in the study area, I calculated the percentage of each planning area that lies within the study area. The result shows that the planning areas were either 100% - 49.3% within the study area or only with a maximum of 6% (see script 1). Hence, only the planning areas that lie at least 49% within the study area are retained in the planning area layer. The study area thus consists of 145 planning areas. To be able to aggregate all three traffic area types per planning area, the information about the planning area ID was implemented in the datasets. To do this, I assigned the segments to the planning areas depending on the (spatial) geometry of the planning areas.

7.2.1 Appendix 2.1 – Data Processing: On-street Parking Spaces

Before completing the missing length and width information of the on-street parking segments, two corrections must be made to the existing data. First, since some parking width of the 'processed' data is missing even though the orientation is recorded, I added the default width values by the OSM-parking-space-project (Seidel & OpenStreetMap-Contributors, 2021) for the respective specified parking orientation. Second, there are some segments specified as 'not processed yet' which already have an accompanying 'processed' segment on the right location. I tried excluding all of the "wrong" 'not processed yet' segments by setting a buffer around the 'processed' segments and excluded the buffer intersecting 'not processed yet segments'. With an additional condition, I avoided that the locally wrong segments intersecting with the buffer were excluded. The condition is that the column 'source capacity' (in my dataset: 'source_c_1') needs to have the value 'OSM', since these are the segments, that are added as 'processed' to the dataset, while the former 'not processed yet' segments are not excluded yet. The correction resulted in the lengths and widths information of only 6.5% of the 'not processed yet' is missing. With the 6% of segments labeled as 'data missing', a total of 12.4% of the length and width information is missing.

7.2.2 Appendix 2.2 – Data processing: Roadways

Some data corrections to create a roadway dataset needed to be made. Firstly, sometimes there was no effective road width, even though, a road width and an on-street parking space width existed. For that, I subtracted the on-street parking space width from the road width. Secondly, some road ('highway') types have negative effective width values, which I measured in QGIS and then decided to reverse their sign. Third, some roadway widths are 0, in which case I use the effective roadway width of the neighboring geometry again. Outliers with very wide roadway width values were divided by 10, as this came closest to the width I measured in QGIS roadway width. Fourth, I have subtracted OSM bicycle parking spaces (imported by the 'QuickOSM' (Version

1.17.1) plugin in QGIS (Version 3.36.1) from the roadway, as these are not yet included in the dataset of parking segments, but sometimes lead to narrower streets.

7.3 Appendix 3: Assessing the Moderate Traffic Area Potential

7.3.1 Appendix 3.1 – Explanation of the On-Street Parking Space Exceptions

To determine the moderate traffic area potential, I first decided on three exceptions where cars can still be parked <u>on-street</u> in the study area. The exceptions I defined are 1.) Car-sharing cars, 2.) Taxis, 3.) Cars for people with restricted mobility. The three exceptions are mainly based on the draft law from the initiative "Volksentscheid Berlin Autofrei" (Berlin Car-Free Referendum) of 2021. They aim to reduce deaths and injuries from motorized traffic, decrease health-threatening emissions (noise and air pollution), and create a liveable city center (Initiative Volksentscheid Berlin autofrei, 2021).

According to the law draft, most public roads (except for privately owned roads, (federal) trunk roads, and pedestrian zones) within the study area should be car-reduced. Therefore, they should be mainly used by pedestrians, cyclists, and local public transport (Initiative Volksentscheid Berlin autofrei, 2021). In contrast, cars must have permission to participate in road traffic for both, driving and parking. Cars for public purposes (police cars, ambulances, etc.) and taxis are generally allowed. Other vehicles need special use permissions for driving on car-reduced roads and on-street parking. Special uses are, for example, commercial- or freight transport or the use of motorized vehicles by or for persons with personal mobility impairments. A limited number of private transport (e.g., relocation) or recreational journeys per year may also be permitted. Lastly, there are hardship regulations for situations where people cannot use bikes or local public transport (ibid.).

To determine which cars are ‘permitted’ to park in on-street parking spaces in my moderate area potential, I made the following assumptions: First, vehicles for public purposes, such as ambulances or police cars, don’t need on-street parking spaces, as they stop of the road when on duty. Taxis, on the other hand, should be available in on-street parking spaces all over the city, which is why I assign on-street parking spaces to them. Second, commercial- or freight transport is also not considered in my on-street exceptions because these vehicles also typically stop on the road. Third, the article on using cars by or for people with personal mobility impairments is included by assigning one on-street parking space available per person with restricted mobility. Such on-street parking spaces have also been created in Oslo’s traffic-calmed city center (Tennøy & Hagen, 2020). Fourth, according to the article on private driving, I assume that these journeys can be made with car-sharing cars. This decision is underlined by the fact that only 26% of journeys are made by private motorized transport in Berlin (Gerike et al., 2020); thus, fewer cars are needed to meet the current demand. Lastly, 'Hardship regulations' are not considered for simplicity reasons. However, car-sharing services and occasional passenger transport (taxis, Uber, etc.) may cover the demand for cars in cases of hardship. In addition, as one on-street car parking space is available per person with reduced mobility, and this assumption may be an overestimate, I consider hardship reasonably covered.

7.3.2 Appendix 3.2 – Estimation of the Number of the 'Permitted' Vehicles

There are about 8,000 taxis in Berlin (as of 2022) (BerlinOnline GmbH, 2024). Although the inner circle accounts for only around 10% of Berlin's total area, the population density is around three times higher in Berlin's center (as of 2021) (SenStadt, n.d.). I am therefore assuming half of the taxis in the whole of Berlin, i.e. 4,000 in the study area, and thereby tend to overestimate the value. The overestimation accounts for the possibility of higher taxi usage than at present.

The same applies to the second on-street car parking exception, i.e. car-sharing cars. There are also around 8,000 car-sharing cars in Berlin (provided by SenMVKU, 2024) and I assume that half (4,000) of them are used in Berlin's center. To further support this approximation, I counted the car-sharing company "Miles" cars in eight of the 145 planning areas and extrapolated this to all planning areas. It resulted in 3,200 cars in the study area from the company 'Miles'. As there are also other car-sharing companies in Berlin (provided by SenMVKU, 2024), the assumption of 4,000 cars may be reasonable.

For the third exception – parking spaces for people with restricted mobility – I assumed one on-street parking space available per person with restricted mobility, based on information from a 2018 population survey in Berlin (Gerike et al., 2020). According to that, about 5.3% (Gerike et al., 2020) of the 1,140,022 residents (as of 2022) (provided by AfS, 2023) in the study area are restricted in mobility. That results in around 60,421 vehicles.

7.3.3 Appendix 3.3 – Calculation of the On-Street Parking Space Requirement

To calculate how much space a car parking space takes up, I took the assumed values from the OSM-parking-space-project. For parallel parking, 2 m width and 5.2 m length are assumed, and the required distance between two vehicles is already considered (Seidel & OpenStreetMap-Contributors, 2021). This results in a parking space requirement for parallel parking of 10.4 m² per car. For perpendicular parking, a width of 5 m and a length of 2.5 m is assumed, which results in a 12.5m² parking area requirement for one perpendicular parking car. Diagonal parking is assumed to consume 13.95 m² per car, with a width of 4.5m and a length of 3.1m (ibid.). For the sake of simplicity, I have added the three area requirements together and calculated an average value. However, to give more weight to parallel parking, as it is the most occurring parking orientation, I have doubled the space requirement for parallel parking.

This results in the following calculation:

$$\frac{\left((10.4m^2 * 2) + 12.5m^2 + 13.95^2\right)}{4} = \ 11.81m^2$$

Thus, a parking space requirement of 11.81 m² is assumed per car.

The resulting on-street parking space requirement for taxis is ~4.72 ha; for car-sharing cars, it is ~4.72 ha as well, and for cars owned by people with restricted mobility, it is ~71.36 ha. The sum of these three parking space requirement exceptions, therefore, is 80.8 ha.

7.4 Appendix 4: Results 3 – Relations in Conversion Option 2 and 3

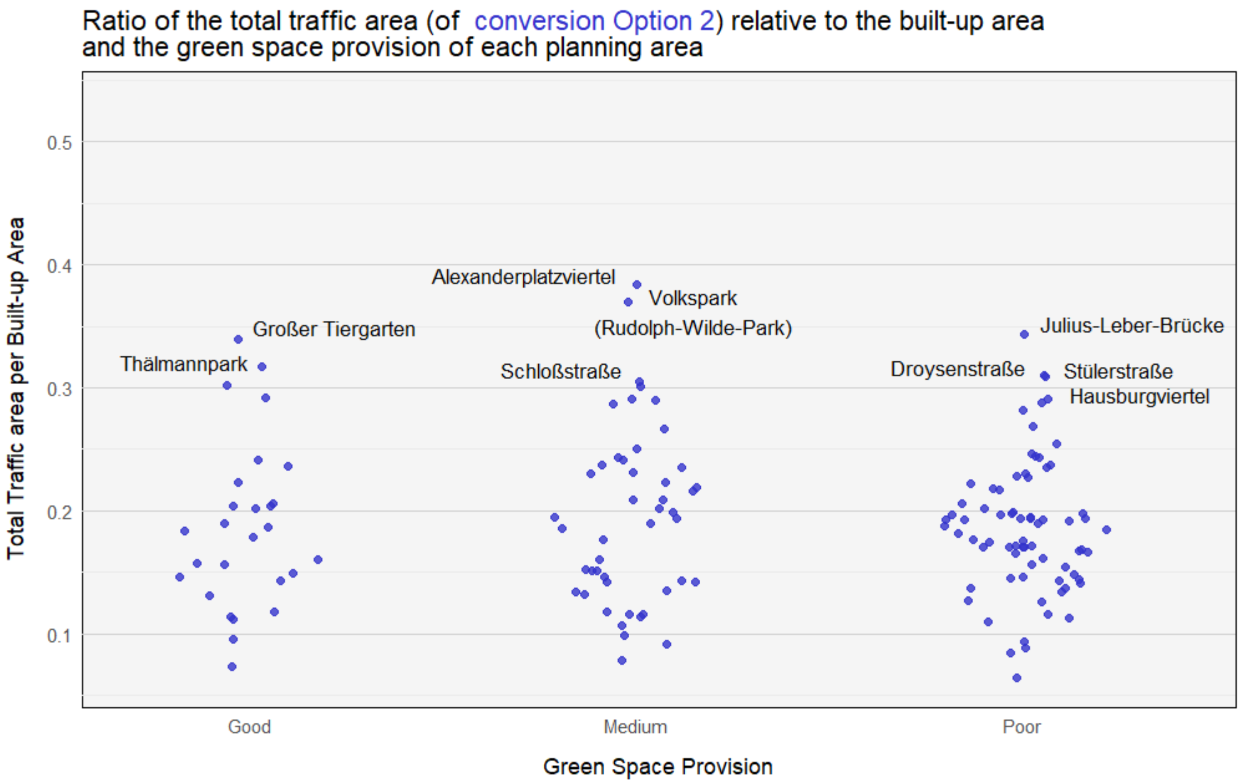

Figure S11: Ratio of A) the relative traffic area values of all three traffic area types (y-axis) of Option 2 and B) the green space provision (x-axis) of all planning areas in the study area. *The traffic area is shown relative to the built-up area. High relative traffic area values indicate that much of the built-up land is used for transportation infrastructure. Labeled planning areas have relative traffic area values in the top 95th percentile of all traffic area values. Own visualization based on 1) data from OpenStreetMap (OSM) and the dataset "parking segments" provided by OpenStreetMap contributors (n.d.b); 2) the built-up area as classified after IÖR (n.d.) and obtained from Berlin's land-use map provided by SenStadt (2022); and 3) the environmental justice map Green Space Provision provided by SenMVKU (2022).*

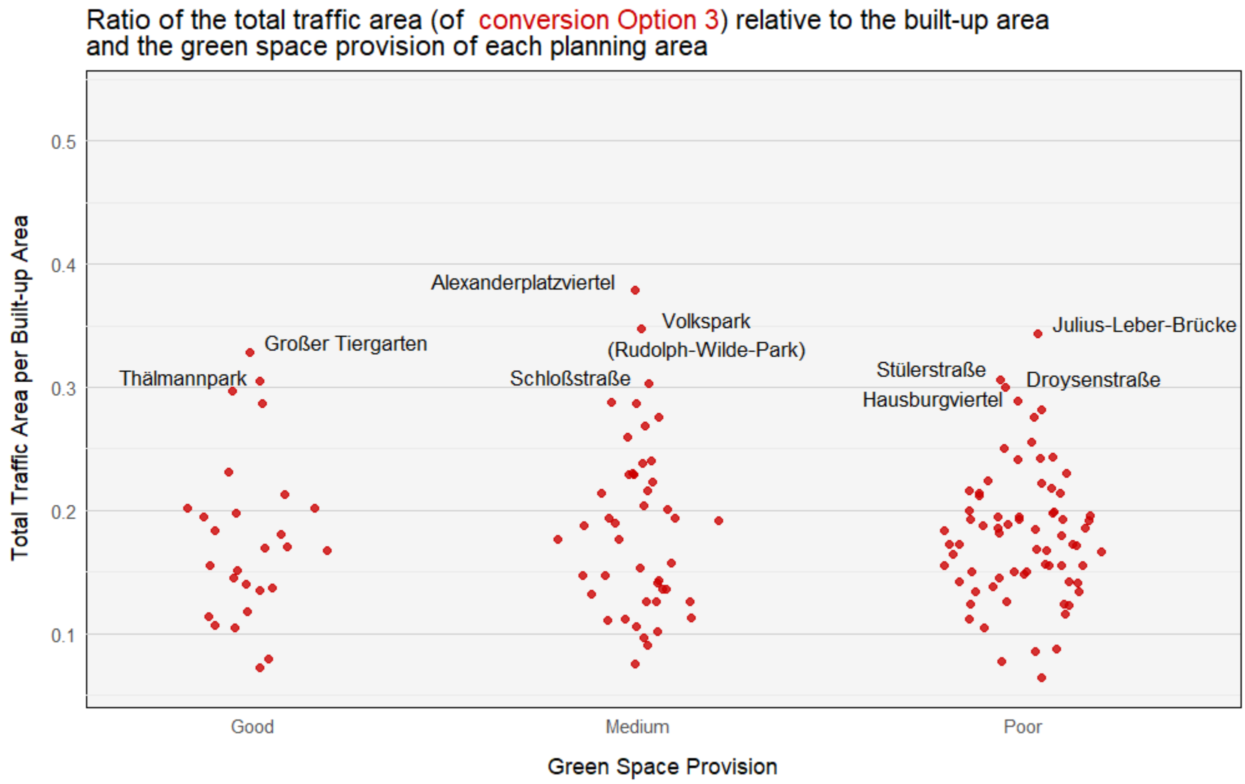

Figure S12: Ratio of A) the relative traffic area values of all three traffic area types (y-axis) of Option 3 and B) the green space provision (x-axis) of all planning areas in the study area. *The traffic area is shown relative to the built-up area. High relative traffic area values indicate that much of the built-up land is used for transportation infrastructure. Labeled planning areas have relative traffic area values in the top 95th percentile of all traffic area values. Own visualization based on 1) data from OpenStreetMap (OSM) and the dataset "parking segments" provided by OpenStreetMap contributors (n.d.b); 2) the built-up area as classified after IÖR (n.d.) and obtained from Berlin's land-use map provided by SenStadt (2022); and 3) the environmental justice map Green Space Provision provided by SenMVKU (2022).*

7.5 Appendix 5: Three Options for Converting Traffic Areas

7.5.1 "No-traffic" – Option 1

In Option 1, the maximum area potential of the traffic area is released for conversion. Despite the numerous benefits associated with a walkable and cyclable urban environment (Turel & True, 2013), the development of cities since the beginning of the modern era has been primarily focused on cars (Southworth, 2005; Newman et al., 2015). This made it possible to travel longer distances more quickly, leading to the growth of cities that no longer serve as solely walkable cities (Southworth, 2005). Furthermore, some motorized vehicles are indispensable in cities, such as ambulances, police cars, fire trucks, delivery vans, etc. In addition, a city without motorized traffic particularly requires comprehensive public transportation (Jensen et al., 2021). However, public transport is limited in Option 1, which means that either the traffic areas for road-based public transport must be retained or non-road-based public transport must be expanded.

On the other hand, many of the World Health Organization's (WHO) 'healthy urban planning' objectives (Barton & Grant, 2011) may be achieved by eliminating motorized traffic. In the following sections, I refer to these objectives, which can be summarized as follows: 1. promoting a safe and healthy environment, 2. promoting active lifestyles (especially regular exercise) and social cohesion and 3. providing everyone with access to high-quality housing and educational, cultural, and leisure facilities (Barton & Grant, 2011).

First, banning motorized traffic from Berlin's center can promote a safe and healthy environment. One reason is that deaths and injuries from road traffic crashes remain one of the most serious global health and development challenges (WHO, 2023). In Berlin, there were around 134,000 traffic crashes in 2023, mainly caused by cars and mainly at the expense of pedestrians and cyclists (Polizei Berlin, 2024), which may be prevented by Option 1. In addition, noise and air pollution would be significantly reduced, as traffic is one of the primary sources of both (EEA, 2020; WHO, 2024). One of the most dangerous pollutants for human health, particulate matter, is emitted directly by cars (Khreis, 2020), and limits are sometimes significantly exceeded on Berlin's main roads (SenMVKU, 2016). Furthermore, almost 10% of Berlin's population is exposed to traffic noise levels potentially hazardous to health (SenMVKU, 2020). Freeing up traffic can also significantly reduce climate-damaging emissions, such as CO_2, as motorized traffic accounts for large share of them (EEA, 2019).

Second, the entire traffic area could be converted into areas promoting healthy lifestyles and social cohesion. Converting the traffic areas into attractive cycling infrastructure, for example, may promote healthy lifestyles by increasing the physical activity of the residents (Ward Thompson & Silverinha de Oliveira, 2016). In fact, Rojas-Rueda et al. (2013) found that using bicycles as a mobility mode reduces cardiovascular diseases and type 2 diabetes. Additionally, open spaces can facilitate healthy lifestyles by providing space for physical exercises (Ma et al. 2019), especially if they are equipped with sports facilities (Danis et al. 2014). Therefore, converting the off-street parking spaces into areas used for activity may help achieve healthy urban planning, as the WHO proposes. Social cohesion can be strengthened by street markets, green spaces, or sports centers in a neighborhood (Cattell et al., 2008; Dash et al., 2024; Peters et al., 2010). Additionally, urban gardening possibilities (Veen et al., 2016) and features such as seating, shelters, and activities can promote social cohesion by strengthening social relationships (Francis et al., 2012). Depending on the size of the facilities, they may be created by converting the traffic areas. In line with that, the Berlin Strategy 2030 guidelines propose integrating green spaces into various construction and development measures (Senatskanzlei Berlin, 2022). For example, neighborhoods should create urban gardens and include green spaces in bicycle infrastructure, sports fields, and playgrounds (Senatskanzlei Berlin, 2022).

Converting the traffic areas may also provide access to high-quality housing and educational, cultural, and leisure facilities. The decision on which conversion is most suitable for different areas in Berlin's center may depend on demand. Urban planning and development must ascertain the specific requirements for a location and determine which conversion is most beneficial. In Berlin, for example, one of the most urgent needs is affordable housing (Senatskanzlei Berlin, 2022), which needs to be considered when dealing with such a large amount of convertible area. Education and leisure opportunities can additionally be provided by green spaces such as parks (Ma et al., 2019). For example, Doyle and Krasny (2003) found that urban gardening can promote young people's understanding of gardening, science, and research. As part of leisure activities, green spaces can also contribute to the recreation of city dwellers (Elmqvist et al., 2015; Lee et al., 2015).

7.5.2 "Traffic-calmed with open spaces" - Option 2

Converting traffic areas into urban green spaces (UGSs) can particularly positively affect urban residents because of the proximity of traffic areas to the places where people live and spend their time and their connectivity. Having UGSs nearby can encourage physical activity by increasing the visitation rate (Coombes et al. 2010). In addition, nearby UGS can particularly promote social cohesion and interaction (Cattell et al. 2008; Francis et al. 2012), as people may feel connected to these places (Maas et al. 2009). Furthermore, the cooling effect of urban green spaces (UGS) is most substantial in their immediate vicinity (Shanahan et al., 2015). Greening the convertible roadway areas and some of the adjacent on-street parking spaces can additionally increase the attractiveness of the roads (also for pedestrians and cyclists), encouraging people to choose one of these active mobility modes (WHO, 2018).

A green network can also provide residents with various opportunities comparable to large green spaces (Sugiyama et al., 2010; Ammon & Langenbrinck, 2022). For example, it might serve as a running route even though the sizes of the individual spaces are relatively small (Ammon & Langenbrinck, 2022). Hartig and Lindal (2021) additionally point out that a broad network of small green spaces is more likely to contribute to recreation than larger green spaces in the periphery. Furthermore, a green network is highly correlated with species richness (FitzGibbon et al., 2007) because it can serve as green corridors (Vergnes et al., 2013) and stepping-stone biotopes (Carbó-Ramirez & Zuria, 2011). A greater biodiversity in urban areas can positively affect the residents' health, e.g., by positively influencing the perceived ability to recover (Lorenzo et al. 2016).

In addition to converting parts of the on-street parking spaces and the roadway area, Option 2 provides for converting 100% off-street parking spaces. Hence, areas between 8 m² and 1.9 ha can be converted. Converting the off-street parking spaces into open spaces may provide residents with a wide range of opportunities, such as sports and play activities, nature experiences, and the opportunity to be alone because of their size (Ward Thompson & Silverinha de Oliveira, 2016). In fact, 32 of the 2,015 off-street parking spaces in the study area may serve as 'Neighborhood Green', as they exceed the minimum size of 0.5 ha summarized by Rittel et al. (2014). 'Neighborhood Green' can be used in various ways, such as play areas for children, quiet zones, or meeting places for different social groups (Rittel et al., 2014). Additionally, thirty of the spaces may serve as 'nature experience areas' (Ger.: Naturerfahrungsräume), as they exceed the size of 0.54 ha of an existing nature experiencing area in Berlin (Pankow) (Molitor & Martens, 2021). Nature experience areas are primarily intended to allow children in large cities to encounter and experience nature (Friede et al., 2020). On the other hand, if traffic is calmed in Berlin's center, off-street parking spaces may be needed, such as parking spaces for delivery vehicles or scheduled buses when not in use.

7.5.3 "Calmed-Traffic" – Option 3

One possible solution is keeping the largest off-street parking spaces as they are while converting the remaining into pocket parks. Pocket parks are becoming increasingly important in cities due to the increasing building density (Nordh et al. 2009). Despite their small size, of around 2,000 m², they can increase citizens' physical activity because of their proximity to residences, according to Cohen et al. (2014). Additionally, Nordh et al. (2009) found that some of the smallest parks (< 3,000m²) in their study's sample had the highest restorative function and that even small green spaces can provide the residents a link with nature. If it is assumed that the largest off-street parking spaces remain as such, 1,946 of the 2,015 off-street parking spaces can be converted into pocket parks, for example. Their sizes range between 8 m² and 3,100 m². This approach results in many pocket parks at many different locations in the study area, which can increase their frequency of use. On the other hand, as described above, larger green spaces can offer the population more opportunities for use. This, in turn, would suggest that the smallest off-street parking spaces remain parking spaces and the largest are converted into green spaces.

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