Peer-reviewed version available at *Infrastructures* **2018**, *3*, 21; doi:10.3390/infrastructures3030021

*Research Paper*

# Spatial Differentiation of the Public Transport Modal Split for Integration into the Location Analysis for Charging Infrastructure

**Waldemar Brost [1,*], Teresa Funke [1] and Michael Lembach [1]**

[1] Chair and Institute of Urban and Transport Planning, RWTH Aachen University; brost@isb.rwth-aachen.de; funke@isb.rwth-aachen.de; lembach@isb.rwth-aachen.de
* Correspondence: brost@isb.rwth-aachen.de; Tel.: +49-241-80-25235

**Abstract:** The spread of charging infrastructure (CIS) for battery electric vehicles is crucial for coping with the increasing number of electric vehicles. Therefore, the selection of ideal (fast-) charging locations determines acceptance, utilization and, thus, the economic viability of a single site or the whole charging network. The methodology of the Integrated Model Approach STELLA[1] for site identification of CIS uses proven methods of traffic modeling such as the classic four-step traffic modeling in a new context to enable statements regarding the positioning of CIS. Based on different spatial analyzes and characterizations of urban quarters, traffic generated by individuals is calculated using the FGSV approach of 2010. Because only (electric) motorized individual traffic is of importance for CIS, the share of trips is calculated by differentiating the modal split between various transport groups. One approach is to concretize the modal split share of public transport based on analyzes of different criteria and data sets, e.g. the accessibility of stops. The model approach STELLA, which also combines various extensive data (e.g. transport networks and traffic volumes, settlement structures, vehicle characteristics, power supply data and user requirements), is currently developed for a planning area covering the entire territory of the Federal Republic of Germany.

**Keywords:** site identification; electric charging infrastructure; electromobility; spatial analysis; modal split; public transport

## 1. Introduction

A prerequisite for the spread of electromobility is the access to charging infrastructure (CIS). Additionally to CIS located in private areas, which is how currently 92% of electro mobile road users have it at their disposal [14], CIS positioned in public areas is not only important for public perception, but also especially for providing basic care and service in case of unplanned charging events. At the latest when entering the mass market, the currently high proportion of private CIS can no longer be assumed. During the determination of potential for the expected CIS utilization within the model approach STELLA, it is crucial to distribute the arising trips made by individuals according to trip generation and trip distribution as accurately as possible to the different transport modes. This modal split of the trips can vary depending on the location and other accompanying circumstances, such as different transport offers. The outcome of the detailed modal split analysis for public transport can then be used in two ways: On the one hand, spatially differentiated public transport shares can be integrated into the model approach STELLA by means of specific analyzes of the public transport service; on the other hand, statements on the quality of service provided by public transport can also be derived on basis of these data.

[1] STELLA is the acronym for the German term "STandortfindungsmodell für ELektrische LAdeinfrastruktur".

Peer-reviewed version available at Infrastructures 2018, 3, 21; doi:10.3390/infrastructures3030021

## 2. Modeling Methodology STELLA

### 2.1. Model Approach

There are various approaches in the literature dealing with the positioning of CIS for electric vehicles. These either consider spatial criteria of a single city or a single region or concentrate on the mobility behavior of the users. Simultaneous consideration of the questions on the positioning as well as the quantification of the CIS for each location is only covered to a limited extend in existing literature within a theoretical environment. This is different in the case of the developed site selection model for electric CIS STELLA, which is based on methods and data structures of the classical traffic modeling.

In this model approach, different indicator groups are compiled, on the one hand, for the description, and on the other hand, for the spatial localization of the daily mobility of the population in a specialized, nationwide traffic model. The user behavior, the distribution of vehicles, the existing CIS as well as the spatial structures and the existing transport infrastructure form the basis for further calculation steps. Likewise, the modular structure of the model makes it possible to integrate further basic conditions, such as different forecast years or political objectives.

One basis for the model approach STELLA is the determination of the generated traffic volume for each small-scale urban quarter [6], which is formed depending on the 8-digit postcode level (PLZ8). The PLZ8 divides Germany into approximately 82,000 urban districts and represents a differentiated subdivision of the 5-digit postcodes into homogenous territorial units containing, on average, about 500 households [6] each. To determine the volume of the generated traffic in each urban quarter, the FGSV method from 2010 is used, which is, however, modified in the modal split calculation for the model approach STELLA. Within the FGSV method, the traffic volume is determined in a first step depending on the type of urban quarter (residential, mixed and commercial zone). This is divided further by taking into account various influencing factors of the different traffic modes by means of different modal split shares. To be able to apply this approach, which is individually interpretable for single areas (<50 ha), to a nationwide consideration (average built-up area size 29.3 ha), additional datasets and universally interpretable indicators have to be developed and integrated. When determining the public transport share for each of the approximately 82,000 urban quarters, the large-scale spatial structure as well as public transport related attributes like the stop density and characteristics of the public transport service quality in combination with the local traffic interlinkages can serve as guidelines. The results of the modified method for calculating the trip generation including trip distribution that splits the traffic volume between the different traffic modes are incorporated directly into the model STELLA.

### 2.2. Spatial analysis

For the nationwide, spatial localization of the potential for electrical CIS, it is necessary to delineate and characterize the space to consider different prerequisites in the spatial structure. This delineation of space is possible on various levels of resolution, since, depending on the level, different characterizing attributes can be added to the individual areas, for example, as a link to other databases. The following sections provide a brief overview of the different distinctions of the region used in STELLA. The definition, which is relevant for the spatial differentiation of public transport, is also presented.

The administrative division of Germany, for example, into counties, municipalities associations, municipalities or postal codes, can serve as a large-scale delimitation [4]. For the investigation of the potential for electrical CIS, the purely administrative demarcation is not sufficient, since it provides no attributes for the structure of the space. Therefore, a characterization of the communities based on non-administrative characteristics such as centrality, densification or commuter relations is necessary [4]. The Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) within the Federal Office for Building and Regional Planning (BBR) provides appropriate area types, so called "city and municipal types", as shown in Table 1 [1]. These differentiate the municipalities

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 May 2018 doi:10.20944/preprints201805.0299.v1

Peer-reviewed version available at *Infrastructures* **2018**, *3*, 21; doi:10.3390/infrastructures3030021

according to their size or their population as well as the respective central location function in the urban and rural municipality.

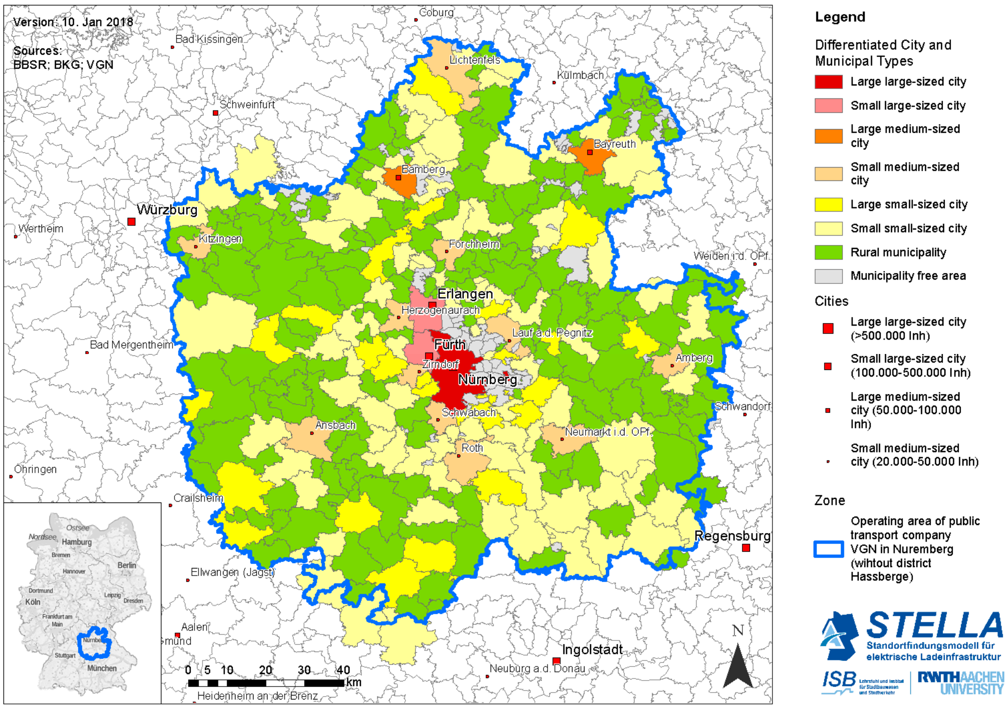


**Figure 1.** City and municipal types in the area of the traffic network metropolitan area of Nuremberg [2] (own depiction based on [1, 2, 20])

**Table 1.** Differentiated city and municipal types [1].

| Denotation | | Population | Central Location Function |
|---|---|---|---|
| large-sized city | large | > 500,000 | usually function of an higher-order center / at least function of a middle-order center |
| | small | 100,000 to 500,000 | |
| medium-sized city | large | 50,000 to 100,000 | predominantly function of a middle-order center |
| | small | 20,000 to 50,000 | |
| small-sized city | large | 10,000 to 20,000 | at least function of a basic-order center |
| | small | 5,000 to 10,000 | |
| rural municipality | | < 5.000 | less then the function of a basic-order center |

This classification provides a baseline for the spatial analysis but cannot cover all properties [2]. Therefore, a further delimitation is introduced which extends the characterization of the municipalities by the classification into "metropolitan regions" at the level of municipalities association. This includes a distinction between the center of a metropolitan region, the supplementary area as well as a closer and further commuter connection space by using commuter movements of employees subject to social insurance contributions between their home and their workplace. The metropolitan regions correspond to the territorial classification of the "urban-rural-regions" [1].

Especially in the context of the definition of the public transport modal split (see chapter 2.4), the "Central Places Concept" (German: Zentrale Orte Konzept - ZOK) [1] represents another relevant categorization. The ZOK is a normative construct for the assignment of services of general interest to

[2] Update 12/2017: District Hassberge is not included due to missing data.

Peer-reviewed version available at Infrastructures 2018, 3, 21; doi:10.3390/infrastructures3030021

cities and municipalities [9] and thus provides clues about the existing or planned infrastructure and institutional equipment of a region [1]. In general, a distinction is made between higher-order centers (supply of specialized higher needs), middle-order centers (supply of upper-level needs) and lowest- / basic- / small-order centers (supply of basic needs). Since the assignment of individual regions to the categories is a task for the federate state planning [1], there are differences in the definitions between federate states and hence differences in the allocation. Among other things, this classification is taken into account for the estimation of the public transport modal split in order to be able to link it to other established considerations and methods of analysis.

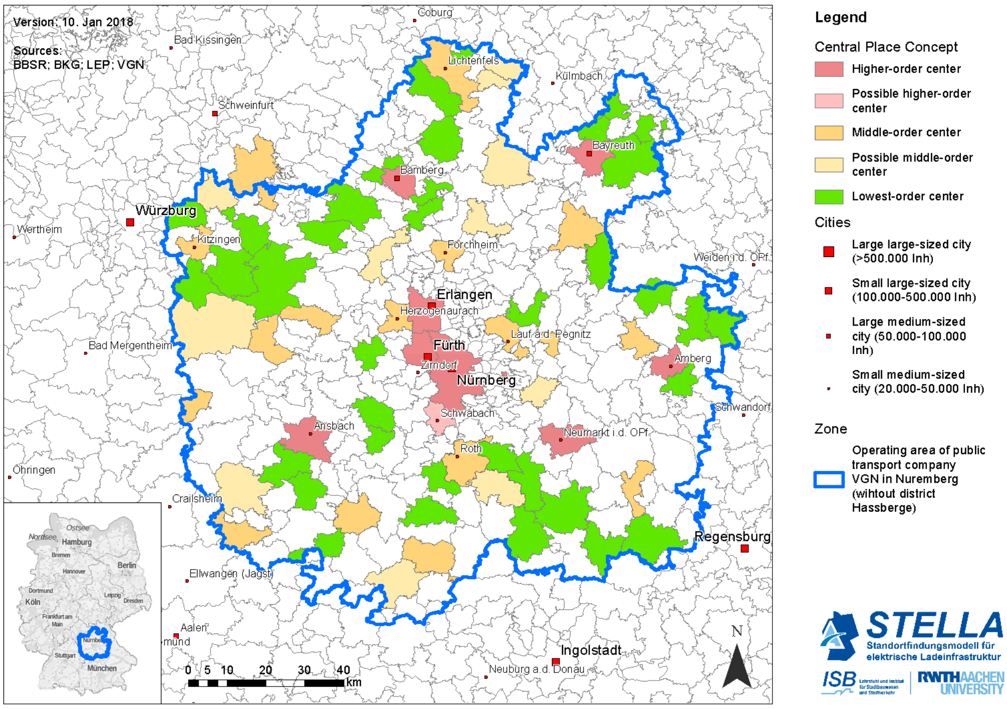


**Figure 2.** Classification of the traffic network metropolitan area of Nuremberg on the basis of the "Central Places Concept" (own depiction based on [1, 2, 12, 20])

Another spatially detailed demarcation is the level of urban quarters (see chapter 2.1) for which the model STELLA calculates the potential for CIS. Each of these urban quarters is classified by linking the large-scale area types described above with the residential and commercial areas, the number of inhabitants, households and employees as well as the building areas in the residential, mixed and commercial zone. The data base used is both open data content and data from commercial providers [BKG, BBSR, DDS, HERE, OSM].

For these derived types of urban quarters, a further differentiation is needed due to the prevailing building typology in different urban space types [10]. A distinction is made between small, detached individual buildings, row, line and block buildings, large-scale housing developments and building structures with a village character. This categorization serves as a baseline for the differentiated determination of the spatial location of an urban quarter within the ZOK, which is in turn linked to the differentiation of the accessibility categories for public transport stops according to Table 2.

### 2.3. Trip Generation

The purpose of the trip generation is to generate undirected trip demand for each unit considered (here: urban quarter). The total number of the on origin-side departing and on destination-side arriving trips for the entire planning area (PA) (in the model STELLA all over Germany) is considered. To calculate the departing and arriving traffic of the individual cells of the

Peer-reviewed version available at Infrastructures 2018, 3, 21; doi:10.3390/infrastructures3030021

PA, a differentiated structural class approach was used whose central input variables represent various structural data (e.g. inhabitants and companies differentiated according to economic groups and employee classes). The procedure is primarily based on the guidelines published by the FGSV in 2010 for estimating the traffic volume.

### *2.4. Methodology for Specifying the Determination of Public Transport Modal Split*

According to the method of the FGSV from 2010, after the step of the estimation of the traffic volume, the differentiation between the groups of non-motorized individual traffic (NMIT), motorized individual traffic (MIT) and public passenger transport (PT) is made. For the estimation of public transport share, the method states different values, which depend, among other things, on the traffic-generating groups (residents, visitors, employees), the city and municipal types, the (non) integrated location of the sites, characteristics of the traffic system or the accessibility of the access points. However, these values sometimes have large spans ("5%-30%" [8] (3.3.8)), are not considered differentiated by the NMIT ("public transport & NMIT share 50%-90%" [8] (3.3.8)) or use vague terms to describe the public transport service ("attractive public transport service"[8] (3.3.8)), so that the estimation of public transport can be influenced by subjective assessments. By analyzing and determining various measurable indicators that influence the share of public transport in a residential district, the estimation of public transport can be objectified and systemized. Thus, when considering a large study area such as the Federal Republic of Germany in the model STELLA, it is possible to develop an algorithm for approximating the spatially differentiated public transport share. By specifying the public transport share, the IT share is also specified indirectly in the model which serves as the basis for the derivation of the electric trips, which, in turn, represent the basis of the potential determination for electrical CIS.

A review of existing literature on the topic shows that a large number of people and institutions already deal with the definition of quality criteria for public transport, which can be used as a guide for the selection and definition of indicators for the development of the algorithm. Not only at the national level but also at European level with the DIN EN 13816 [5], a device was created that deals, among other things, with the description of quality criteria for public transport differentiated into eight categories. However, only possible criteria are named and no limits or guidelines are attached. On the contrary, Schwarze [15] deals in his work in detail with the concept of accessibility, different definitions, indicators and possible guidelines for it. Thus, he differentiates, based on an evaluation of North Rhine-Westphalian local transport plans, for example, between planning accessibility indicators and practically used accessibility indicators. Due to the multitude of quality criteria for public transport, which were detected in our literary research, the focus of this study was on the accessibility of stops in a specific space. The importance of this indicator in the context of concretizing the determination of the public transport modal split is explained in the following sections.

#### 2.4.1. Accessibility of Stops as a Quality Criterion

The indicator of accessibility or, in other terms, the catchment area of stops serves as an indication of the quality of accessibility of public transport. For this aspect, different recommendations in the literature can be found. The VÖV [19] differentiates in its recommendation for an appropriate standard of public transport service between the transport mode groups metro & suburban train & local passenger rail traffic and bus & tram. Depending on a subdivision of the Central Places Concept regarding the spatial location as relative to the core area, distances between 300 m and 1,200 m are considered adequate. About 20 years later, the VDV [18] recommends the distances for reasonable beeline for the same transport groups between 300 m and 1,000 m, depending on the density of use within the ZOK. The lower maximum distances indicate a higher demanded standard of development over the years. In addition to recommendations at the federal level, the Bavarian State Ministry for Economic Affairs, Infrastructure, Transport and Technology [16] also offers specified information on the catchment areas of stops in its guidelines on urban transport planning in Bavaria. In this case, a distinction is made between guide values (between 300 m and 1,500 m) and upper limits (between 400 m and 1,800 m) per group of vehicles. The FGSV

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 May 2018 doi:10.20944/preprints201805.0299.v1

Peer-reviewed version available at Infrastructures 2018, 3, 21; doi:10.3390/infrastructures3030021

[7] uses a slightly different approach to public transport accessibility in their planning aids for urban land-use planning, which is due to the fact that no recommendation but an assessment scheme for individual locations is presented. Therefore, various qualitative grades are listed in terms of the distance to stops. In contrast to the above-mentioned approaches, in this approach, the transport modes are divided into bus and local rail transport.

Based on these four sources, the quality levels (QL) shown in Tables 2 and 3 were developed. The QL 1 is based on the recommendations of the VÖV, the VDV and the benchmarks of the Bavarian Ministry of State, which differ only in individual categories. The basis for the QL 2 are limits of the Bavarian urban transport planning, while taking into account the limits of the upper three categories of the FGSV at the same time. Another survey of eleven Hessian local transport plans carried out by Winter [22] has a similar scale of assessment for station access levels to the other sources. Deviations occur in the Hessian local traffic plans, in particular for the accessibility for metro/suburban train and the local passenger rail traffic, for which the analysis itself already contains a large span of values.

**Table 2.** Quality levels of accessibility (beeline) of public transport stops (unit meters) (own depiction based on [7, 16, 18, 19])

| **Denotation** | | **Bus / Tram** | | | **Metro / Suburban Train / Local Passenger Rail Traffic** | | |
|---|---|---|---|---|---|---|---|
| | | **QL 1** | **QL 2** | **QL 3** | **QL 1** | **QL 2** | **QL 3** |
| large-sized city | core zone | ≤ 300 | ≤ 400 | > 400 | ≤ 400 | ≤ 600 | > 600 |
| | high density area | ≤ 400 | ≤ 500 | > 500 | ≤ 600 | ≤ 800 | > 800 |
| | low density area | ≤ 600 | ≤ 800 | > 800 | ≤ 1000 | ≤ 1200 | > 1200 |
| medium-sized city | core zone | ≤ 300 | ≤ 500 | > 500 | ≤400 | ≤ 600 | > 600 |
| | high density area | ≤ 400 | ≤ 800 | > 800 | ≤ 600 | ≤ 800 | > 800 |
| | low density area | ≤ 600 | ≤ 800 | > 800 | ≤ 1000 | ≤ 1200 | > 1200 |
| small-sized city | central area | ≤ 400 | ≤ 500 | > 500 | ≤ 600 | ≤ 800 | > 800 |
| | remaining area | ≤ 600 | ≤ 800 | > 800 | ≤ 1000 | ≤ 1200 | > 1200 |
| municipality | | ≤ 600 | ≤ 800 | > 800 | ≤ 1000 | ≤ 1200 | > 1200 |

In addition to the recommendations for the distances to stops, which usually refers to beelines, there are sources in the literature, that set a maximum for the walking distances, so the actual covered path. Both Boesch [3] and UVEK [17] suggest 600 m as the maximum walking distance to bus or tram stops and 1,500 m to train stops. However, since no spatial differentiation is listed here, it can be assumed that, like in the other sources, certain variations in the recommended distances between the core and the peripheral zones are possible. These limits are also taken into account when defining the quality levels. A significant transgression of up to 500 % above the maximum values of the evaluation scheme of the FGSV [7] is excluded for the development of the QL, since the actual use of such stops at a distance of 3 km or a walking time of about 51 minutes is questionable. In this case, the conversion from the spatial distance to the time required for this purpose is calculated using the average speed of 1.17 m/second (70 m/minute) that is used in both the recommendations of the VÖV [19] and the VDV [18]. As Weidmann already pointed out in 1922, a variety of information on the pedestrian speed can be found in the literature, but in some cases these differ significantly. The speed used in the recommendations is slightly below the average speed of 1.34 m/seconds that was suggested by Weidmann [21]. However, the speed can be influenced by characteristics of the pedestrian, accompanying circumstances of the movement as well as characteristics of the infrastructure [21].

*Preprints* (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 May 2018 doi:10.20944/preprints201805.0299.v1

Peer-reviewed version available at *Infrastructures* **2018**, *3*, 21; doi:10.3390/infrastructures3030021

The factor of 1.2 used by the VDV is also used for the required detour factor for the general approximation of the real walking distance based on the beeline distance, even though differences due to, for example, different trip purposes are possible [17]. A conversion of the quality levels into walking time, as presented in Table 3, shows that the 5 to 10 minutes recommended in the literature for stops of different means of transport [22] in QL 1 were predominantly met. For the QL 2, this is also partially true for the core areas. Exceptions are peripheral areas of the lowest-order centers as well as rural municipalities.

**Table 3.** Quality levels of accessibility (walking time) of public transport stops (unit minutes) (own depiction based on [7, 16, 18, 19])

| Denotation | | Bus / Tram | | | Metro / Suburban Train / Local Passenger Rail Traffic | | |
|---|---|---|---|---|---|---|---|
| | | QL 1 | QL 2 | QL 3 | QL 1 | QL 2 | QL3 |
| large-sized city | core zone | ≤ 5 | ≤ 7 | > 7 | ≤ 7 | ≤ 10 | > 10 |
| | high density area | ≤ 7 | ≤ 9 | > 9 | ≤ 10 | ≤ 14 | > 14 |
| | low density area | ≤ 10 | ≤ 14 | > 14 | ≤ 17 | ≤ 21 | > 21 |
| medium-sized city | core zone | ≤ 5 | ≤ 9 | > 9 | ≤ 7 | ≤ 10 | > 10 |
| | high density area | ≤ 7 | ≤ 14 | > 14 | ≤ 10 | ≤ 14 | > 14 |
| | low density area | ≤ 10 | ≤ 14 | > 14 | ≤ 17 | ≤ 21 | > 21 |
| small-sized city | central area | ≤ 7 | ≤ 9 | > 9 | ≤10 | ≤ 14 | > 14 |
| | remaining area | ≤ 10 | ≤ 14 | > 14 | ≤ 17 | ≤ 21 | > 21 |
| municipality | | ≤ 10 | ≤ 14 | > 14 | ≤ 17 | ≤ 21 | > 21 |

Based on the defined quality levels of the accessibility of public transport stops, a spatial analysis can be carried out. Depending on the proportion of covered settlement area per quality level, the modal split share of public transport can then be influenced in the FGSV traffic estimation method. However, accessibility is only one of many indicators influencing public transport and will be combined with the influences of other indicators in later steps.

### 2.4.2. Evaluation of the Quality Criterion of Accessibility for the Model Region VGN

As a model region for the first analyzes of public transport, the network of the metropolitan area of Nuremberg is chosen. On the one hand, this is due to the spatial structure and the existing public transport service. On the other hand, all pieces of information about stops and timetables are available online for free use [20]. The interconnected area of the VGN shows all different categories of city and municipal types, the ZOK and the different urban space types (see chapter 2.2) as well as the different means of transport: bus, tram, metro, suburban train and regional train.

The location-specific indicator of public transport stops is the focus of these studies. The quality is assessed based on the proportion of settlement area covered by public transport in comparison to the total settlement area per urban quarter. In accordance with the categories listed in Table 2, each urban district is assigned to a category of the ZOK in an upstream analysis, so that, depending on the type of public transport stop (bus & tram or metro & suburban train & local passenger rail traffic) and the QL (1 & 2), reachability distances can be assigned.

The accessibility analysis is carried out using two different methodological approaches. The first method considers distances as accessibility radii (beeline), so that circles with corresponding radii are drawn around each stop. Subsequently, for each urban quarter, the settlement areas covered by the

Peer-reviewed version available at Infrastructures 2018, 3, 21; doi:10.3390/infrastructures3030021

various QL are set in relation to the total settlement area. This method has the advantage that it is easy to implement and gives a homogeneous result. The disadvantage of this is, however, that the radii depict beelines, but the areas covered by these beelines cannot necessarily be reached with the existing network within the estimated ranges. The consideration of possible detour factor can only be applied generally, but the local road and path networks differ significantly is in their directness. For this reason, an accessibility analysis is additionally carried out on the pedestrian-friendly road and path network [11] as a second method. Here, the stops are initially projected onto the next spatial road connection before the reachability distances are routed on the road and path network. In this way, it is possible to determine the areas that can actually be reached and thus the area of settlement actually covered. A schematic representation in figure 3 illustrates these different results of the two methods.

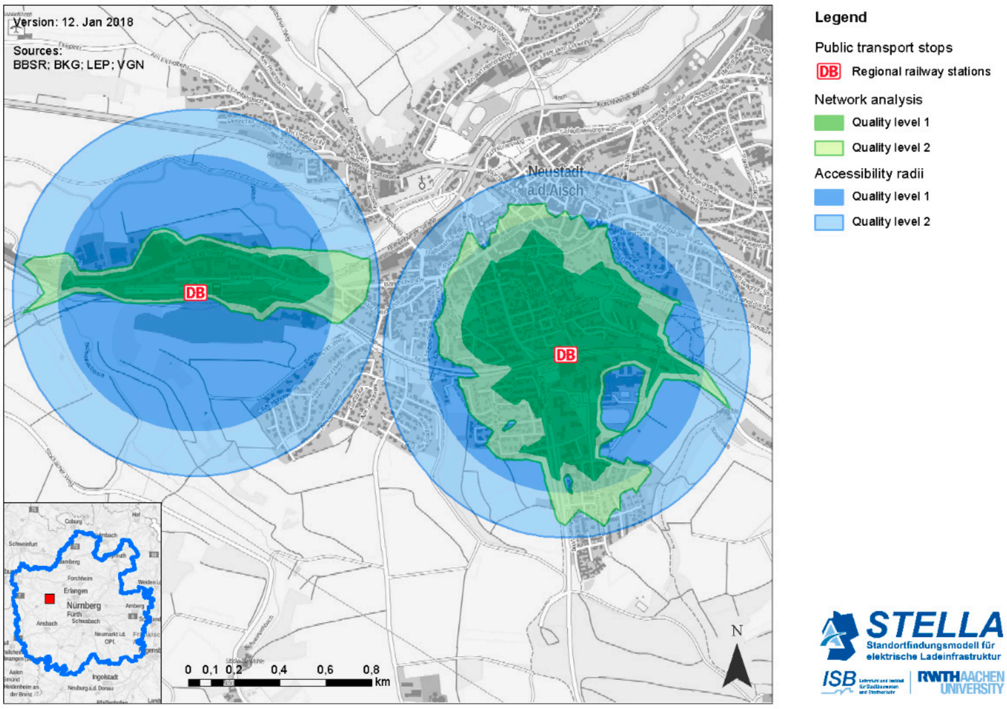


**Figure 3.** Schematic comparison of accessibility radii and network analysis [own depiction]

The evaluation of the covered settlement areas per QL for each method is shown in Tables 4 and 5. According to the information provided by the VDV [18] and other sources, “an area is considered to be developed if 80 % of these people live or work in the catchment areas of stops (…)”. For reasons of simplicity, for now, the assumption is made that the inhabitants would be evenly distributed over the area, which would be considered as developed when 80 % of the settlement area is covered. Moreover, for now, the urban quarter types business, office, administrative and industrial area are excluded. This typing needs a more detailed consideration, as a qualitative assessment of the area is not always useful. In the case of large-scale commercial enterprises, it is not the entire area that has to be reached by a public transport stop but the relevant access points. A pure area-based analysis would therefore adversely affect the results.

Peer-reviewed version available at *Infrastructures* **2018**, *3*, 21; doi:10.3390/infrastructures3030021

**Table 4.** Proportionate coverage of settlement area per urban quarter differentiated by accessibility radii according to quality levels and transport mode group in the operating area of the VGN [own depiction]

| Depiction | | Number of Urban Quarters * | Bus/Tram | | Metro / Suburban Train / Local Passenger Rail Traffic | |
|---|---|---|---|---|---|---|
| | | | QL 1 | QL 2 | QL 1 | QL 2 |
| higher-order center | core area | 120 | 89 % | 98 % | 38 % | 62 % |
| | core edge zone | 425 | 93 % | 98 % | 47 % | 62 % |
| | outer zone | 370 | 96 % | 99 % | 30 % | 41 % |
| middle-order center | core area | 17 | 82 % | 100 % | 0 % | 18 % |
| | outer zone | 25 | 92 % | 100 % | 28 % | 44 % |
| | districts | 344 | 91 % | 94 % | 15 % | 24 % |
| lowest-order center | central area | 12 | 75 % | 83 % | 17 % | 50 % |
| | districts | 310 | 75 % | 86 % | 11 % | 15 % |
| rural municipality | | 1052 | 81 % | 89 % | 14 % | 18 % |

* excluding the urban quarter types business, office, administrative and industrial area

The analysis of the other residential district types (excluding the previously mentioned) using the method of accessibility radii clearly shows that the coverage of areas with stops of the transport system bus or tram within the VGN operating area is fulfilled almost everywhere. In contrast, the availability of stops for rail-bound public transport does not meet the VDV limit of area coverage in any of the spatial categories.

**Table 5.** Proportionate coverage of settlement area per urban quarter differentiated by network analysis according to quality levels and transport mode group in the operating area of the VGN [own depiction]

| Depiction | | Number of Urban Quarters * | Bus/Tram | | Metro / Suburban Train / Local Passenger Rail Traffic | |
|---|---|---|---|---|---|---|
| | | | QL 1 | QL 2 | QL 1 | QL 2 |
| higher-order center | core area | 120 | 51 % | 80 % | 18 % | 48 % |
| | core edge zone | 425 | 69 % | 84 % | 30 % | 48 % |
| | outer zone | 370 | 70 % | 86 % | 16 % | 24 % |
| middle-order center | core area | 17 | 24 % | 88 % | 0 % | 0 % |
| | outer zone | 25 | 64 % | 92 % | 20 % | 28 % |
| | districts | 344 | 58 % | 81 % | 6 % | 13 % |
| lowest-order center | central area | 12 | 42 % | 58 % | 0 % | 33 % |
| | districts | 310 | 37 % | 64 % | 5 % | 7 % |
| rural municipality | | 1052 | 37 % | 69 % | 7 % | 12 % |

* excluding the urban quarter types business, office, administrative and industrial area

A different result can be seen in the analysis of the urban quarter types using the second, network-related method. In this case, it is noticeable that, in terms of the accessibility of bus and tram stops in any of the spatial categories, the complete coverage according to the VDV definition in QL 1 is not achieved. In the QL 2, accessibility decreases as the ZOK and the distance to the core areas

Peer-reviewed version available at Infrastructures 2018, 3, 21; doi:10.3390/infrastructures3030021

increase. Also, the coverage of the settlement area by stops of the local passenger rail traffic is significantly lower or partly no longer available in comparison to the analysis using accessibility radii.

This confirms the previously established hypothesis that the accessibility radii cover a larger area than the network analysis. The differences in the proportions of the covered area have spans between 6 % and almost 60 %. It is noticeable that the difference in the QL 2 is smaller than in the QL 1. This may possibly be explained by the fact that the higher distances cover a larger share of the settlement area altogether. Likewise, it is also possible that the accessible areas often have a "flatter" and "rounder" shape due to the larger footpath distance than small distances, since, for example, cross connections between two axes that lead straight away from the stop can also be reached and the area is therefore covered. Figure 3 shows that the accessibility of the areas depends on the shape of the roads or the networks. Depending on the network, covered areas form almost a "linear" area along an axis (Figure 3, left example) or become "flatter" and "rounder" (Figure 3, right example) and thus get more similar to the analysis results of the accessibility radii. This comparison makes it clear that the choice of the method of analysis is of particular importance for the evaluation of public transport services. Due to the nationwide available network including the consideration of special routes for pedestrians, further analyzes are carried out by means of network analyzes and thus by means of routed distances.

These results serve as a first indicator to influence the public transport modal split share. If there is no accessibility in respective areas, public transport as an alternative to the individual traffic is only of secondary importance. However, once settlement coverage is established, further analysis of supply may increase the importance of public transport, which in turn becomes apparent in the modal split share and thus influences the FGSV traffic estimation process. Further indicators that can influence the public transport share are currently developed. In addition to criteria of traffic development and the transport service, these also include properties of the potential user groups, such as the socio-demographic or socio-economic status. A review of the calculated impact on the modal split based on surveys and passenger numbers regarding the actual number of trips in public transport is aimed at.

## 3. Model Results of STELLA and Conclusion

The presented analyzes on the spatial differentiation of the public transport modal split are included in the calculation of the traffic volume of the model approach STELLA. One overall modeling result of this approach shows the potential of the expected charges as a function of required charging power and expected length of stay for each urban quarter of the entire planning area "Germany". This result can be reduced to a model-internally comparable rank and then sorted. An iterative calculation, currently under development, can determine the order and the required amount of CIS in the planning area "Germany". The iteration can be limited by variable termination criteria for area coverage and demand.

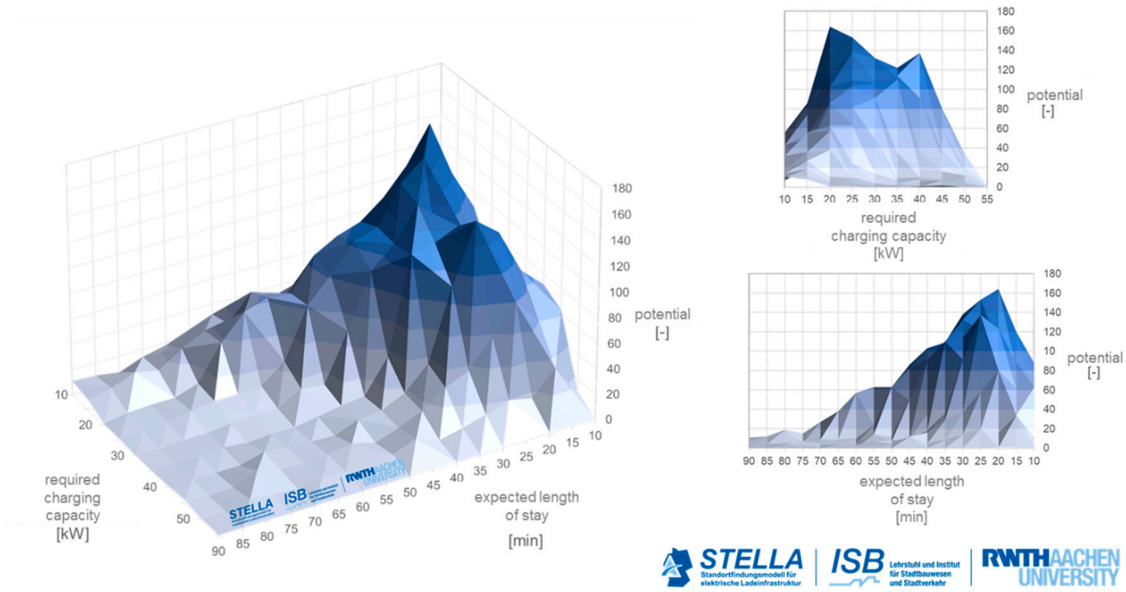


**Figure 4.** Visualization of the charging requirement profile of a urban quarter [own depiction]

The resulting site selection model for electric CIS STELLA forms a tool with broad application in the planning steps of locating, planning and evaluating of single existing or future locations or entire location systems for CIS at the urban quarter level. Specialist planners are the main target group for the usage and interpretation of the model results as well as for the targeted use of the wide range of indicators and their parameterization. Through workshops and, if necessary, additional documentation supplemented by examples of interpretation, even a larger group of people could use the tool for planning.

**References**


1. BBSR 2018: Raumabgrenzungen. Bundesinstitut für Bau-, Stadt- und Raumforschung (Hrsg.), online available at http://www.bbsr.bund.de/BBSR/DE/Raumbeobachtung/Raumabgrenzungen/ raumabgrenzungen_node.html (Access: 02.01.2018).
2. BKG 2018: Open Data – Freie Daten und Dienste des BKG. Bundesamt für Kartographie und Geodäsie (BKG) (Hrsg.), online available at http://www.geodatenzentrum.de/geodaten (Access: 02.01.2018).
3. Boesch, H., 1989: Der Fussgänger als Passagier – Zugänge zu Haltestellen und Bahnhöfen. Institut für Orts-, Regional- und Landesplanung (ORL), ETH Zürich. ORL-Bericht 73/1989. Vdf-Verlag. Zürich.
4. DESTATIS 2015:. GV-ISys – Verzeichnis der Gebietseinheiten. Definitionen und Beschreibungen. Statistisches Bundesamt (Hrsg.).
5. DIN EN 13816: Transport-Logistik und Dienstleistungen. Öffentlicher Personenverkehr. Definition, Festlegung von Leistungszielen und Messung der Servicequalität. Deutsche Fassung EN 13816. 2002.
6. DDS 2014: Datenbeschreibung. PLZ8 Deutschland Grenzen, PLZ8 Deutschland XXL. Digital Services GmbH. Karlsruhe. 2014.
7. FGSV 1999: ÖPNV und Siedlungsentwicklung – Planungshilfe für die kommunale Bauleitplanung. Forschungsgesellschaft für Straßen- und Verkehrswesen e.V. (FGSV). Ausgabe 1999. Köln.
8. FGSV 2010: Hinweise zur Schätzung des Verkehrsaufkommens von Gebietstypen. Forschungsgesellschaft für Straßen- und Verkehrswesen e.V. (FGSV). Ausgabe 2006. Korrektur 2010. Köln. FGSV 147. ISBN 3-939715-06-9.
9. Flex, Florian; Greiving, Stefan; Milstein, Alexander; van Gemmeren, Christoph; David, Carl-Heinz, 2016: Steuerungswirkung und Handlungsfelder eines modernisierten Zentreale-Orte-Konzepts. Arbeitsberichte des ARL, Hannover.
10. Hegger, M., Dettmar, J., Meinberg, T., Drebes, C., Schulze, J., Sieber, S., Sylla, O., 2015: EnEff:Stadt – UrbanReNet Phase 2: Weiterführung und inhaltliche Vertiefung des Forschungsprojektes UrbanReNet – Vernetzte regenerative Energiekonzepte im Siedlungs- und Landschaftsraum. Schlussbericht. Fachgebiet Entwerfen und Energieeffizientes Bauen, FB Architektur, Fachgebiet Entwerfen und Freiraumplanung, FB

Peer-reviewed version available at *Infrastructures* **2018**, *3*, 21; doi:10.3390/infrastructures3030021

Architektur, TU Darmstadt. Förderkennzeichen 0327832E. Gefördert durch Bundesministerium für Wirtschaft und Energie. Darmstadt

11. HERE 2017: Datensatz Deutschland, HERE International B.V. (HERE)
12. LEP o.J.: Anhang 2 – Zentrale Orte und Siedlungsschwerpunkte. Online available at: https://www.landesentwicklung-bayern.de/fileadmin/user_upload/landesentwicklung/Dokumente_und_Cover/Instrumente/s067.pdf (Access: 10.01.2018)
13. OSM 2017: Datensatz Openstreetmap. FOSSGIS e.V.
14. Trommer, S., Jarass, J., & Kolarova, V., 2015: Early adopters of electric vehicles in Germany unveiled. In Proceeding of the 18th International Electric Vehicle Symposium and Exhibition.
15. Schwarze, B., 2005: Erreichbarkeitsindikatoren in der Nahverkehrsplanung. Arbeitspapier 184. Institut für Raumplanung, Fakultät Raumplanung, Universität Dortmund. Dortmund.
16. STMWI 2018: Leitlinie zur Nahverkehrsplanung in Bayern. Bayerisches Staatsministerium für Wirtschaft, Infrastruktur, Verkehr und Technologie (STMWI). Online available at http://www.demografie-leitfaden-bayern.de/fileadmin/user_upload/demografie-leitfaden/dokumente/LEITLINIE98.pdf (Access: 04.01.2018)
17. UVEK 2011: Grundlagen für den Fussverkehr. Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation (UVEK). Forschungsauftrag VSS 2000/368. Bundesamt für Strassen. Zürich.
18. VDV 2001: Verkehrserschließung und Verkehrsangebot im ÖPNV. Verband Deutscher Verkehrsunternehmen (VDV). VDV-Schrift 4. Ausgabe 06/2001. Köln.
19. VÖV 1981: Empfehlungen für einen Bedienungsstandard im öffentlichen Personenverkehr. Verband Öffentlicher Verkehr (VÖV). VÖV-Schriften 1.41.1. Verband Öffentlicher Verkehr, Köln.
20. VGN 2018: Verkehrsverbund Großraum Nürnberg (VGN). Internetpräsenz. Online available at: http://www.vgn.de (abgerufen 04.01.2018)
21. Weidmann, U., 1992: Transporttechnik der Fussgänger – Transporttechnische Eigenschaft des Fußgängerverkehrs, Literaturauswertung. Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau (IVT). ETH Zürich. Schriftenreihe des IVT Nr. 90. 1992. Zürich. https://doi.org/10.3929/ethz-a-000687810
22. Winter, O. M., 2005: Analyse und Evaluation von Nahverkehrsplänen und die Aufstellung von Kriterien zur Bewertung von Standards im ÖPNV. Institut für Verkehrswesen Universität Kassel (Hrsg.). Schriftenreihe Verkehr. Heft 16. Juli 2005. Kassel. ISBN 3-89958-153-9.